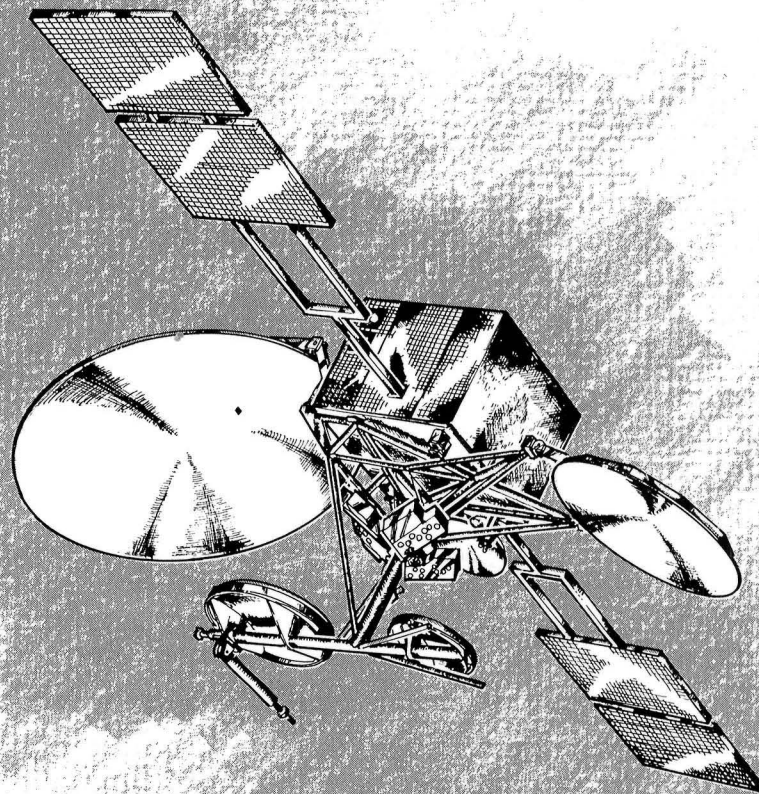


Experiments Applications Guide



Advanced Communications Technology Satellite (ACTS)

NASA TM-100265

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Experiments Applications Guide

Lewis Research Center
Cleveland, Ohio

July 1988

Advanced
Communications
Technology
Satellite (ACTS)



National Aeronautics and
Space Administration

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Introduction



The Advanced Communications Technology Satellite (ACTS) is a key to reaching NASA's goal of developing high-risk, advanced communications technology usable in multiple frequency bands to support our Nation's future communications needs. Realizing this goal will enable growth in capacity and effective use of the frequency spectrum and will maintain the United States preeminence in satellite communications. Using multiple dynamically hopping spot beams and advanced onboard switching and processing systems, ACTS will open new vistas in communications satellite technology.

Key technologies to be validated as part of the ACTS Program include the **multibeam antenna**—a rapidly reconfigurable hopping and fixed spot beam antenna to serve users equipped with small-aperture terminals on their premises; the **baseband processor**—a high-speed digital spacecraft switch to efficiently use transponder capacity (in time and frequency) for routing individual circuit-switched messages; the **microwave switch matrix**—a dynamic reconfigurable switch to route high-volume point-to-multipoint traffic; **rain fade compensation**—techniques such as forward error correction and power control to automatically overcome uplink and downlink signal level changes; and **Ka-band components**—the development of both flight and ground terminal hardware at 20 and 30 GHz.

NASA is striving to attain the widest possible involvement of the United States telecommunications, business, and science communities (industry, government, and universities) in evaluating and testing this advanced technology. Hence the ACTS Experiments Program has been established. This program will make the capabilities of the ACTS system (flight and ground segments) available to the public and private sectors for experimentation. Experimenters will be able to test and evaluate the key ACTS system technologies. The ultimate objective is to stimulate operational applications. A nominal two-year period of experimentation is planned after launch.

The NASA Lewis Research Center is managing the ACTS Project under the Office of Space Science and Applications at NASA Headquarters. General Electric's (GE) Astro-Space Division is the prime contractor for the ACTS flight system; Comsat has been contracted to supply the NASA ground segment. Current schedules place satellite launch in 1992.

This applications guide first surveys the capabilities of the ACTS system—both the flight and ground segments. This overview is followed by a description of the baseband processor (BBP) and microwave switch matrix (MSM) operating modes. Terminals operating with the baseband processor are referred to as low burst rate (LBR); and those operating with the microwave switch matrix, as high burst rate (HBR). Table II (p. 26) describes three very small-aperture terminals (VSAT's)—LBR-1, LBR-2, and HBR—for various ACTS operating modes. The table also describes the NASA Lewis link evaluation terminal. A section on ACTS experiment opportunities introduces a wide spectrum of network control, telecommunications, system, and scientific experiments. Here the performance of the VSAT's is discussed in detail. This guide is intended as a catalyst to encourage participation by the telecommunications, business, and science communities in a broad spectrum of experiments.

System Description

The ACTS system (fig. 1) is made up of a flight segment and a ground segment. The flight segment consists of a multibeam communications package and the spacecraft bus. The ACTS satellite (fig. 2) will be located in geosynchronous orbit at 100° west longitude. In orbit ACTS will "weigh" approximately 2,860 lb and measure 46.5 ft from tip to tip along the solar arrays and 30 ft from one antenna to another.

Separate Ka-band (30/20 GHz) antennas, each with horizontal and vertical polarization subreflectors, are provided for transmitting and receiving signals. The offset Cassegrain antenna system provides two hopping spot beam families (east

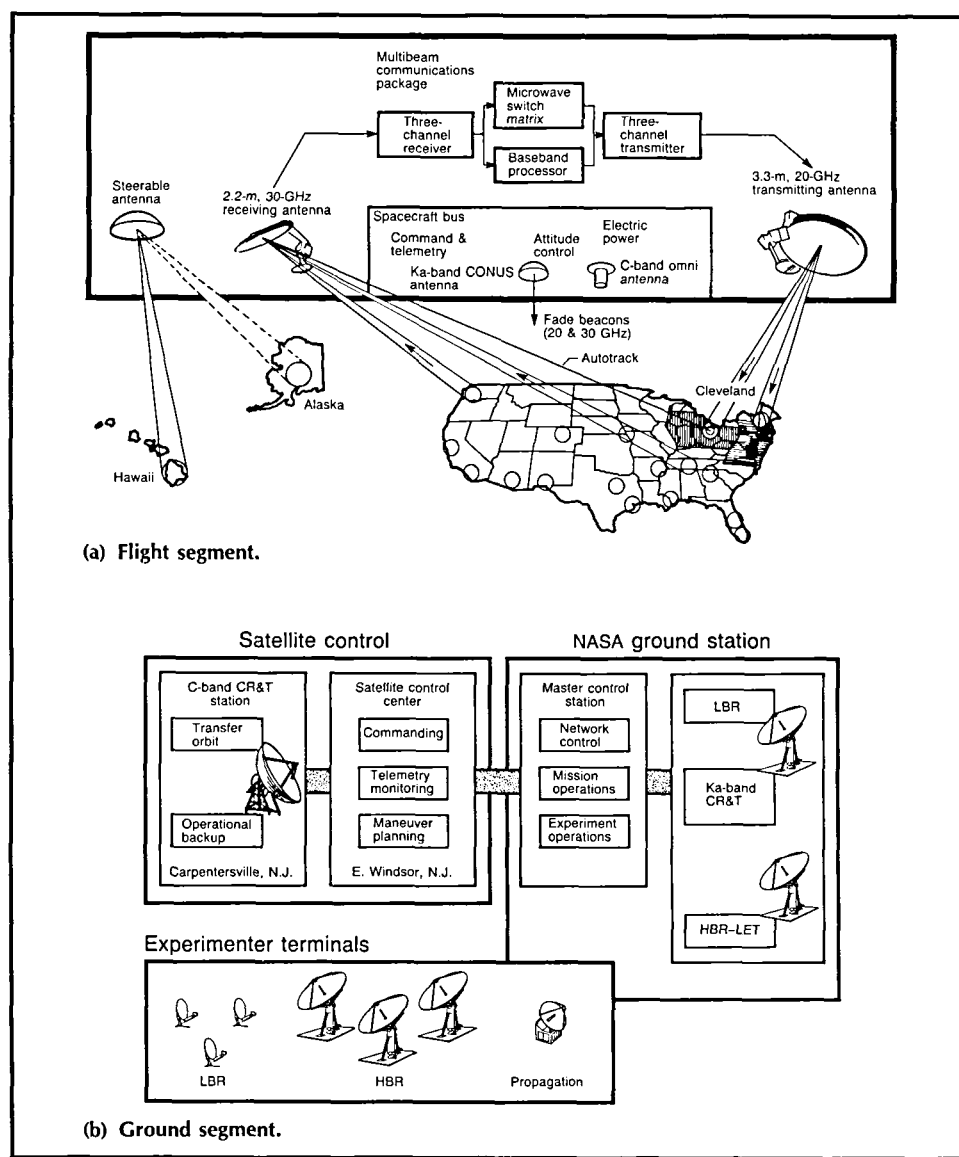


Figure 1.—Functional overview of ACTS system.

and west) plus three fixed spot beams. The east and west families are discriminated by polarization. The east family of beams comprises an east scan sector and additional spot beams for isolated-location coverage outside the sector. The west family comprises a west scan sector, additional spot beams for isolated-location coverage outside the sector, and a steerable spot beam. Within the beams access will be by demand-assigned multiple access (DAMA) using time-division multiple access (TDMA) transmission. The multibeam communications package provides the means for receiving, processing, switching, amplifying, and transmitting signals that carry high-speed digital communications traffic.

A major feature of the ACTS system is its use of dynamic rain fade compensation. The ACTS flight system will incorporate three beacons for real-time fade measurements: two in the downlink frequency band and one in the uplink frequency band. Signals from all three beacons will be transmitted via full continental United States (CONUS) coverage antennas. The downlink frequency beacons at 20.185 GHz (vertical polarization) and 20.195 GHz (horizontal polarization) will be used for telemetry, ranging and power monitoring (fade control), and propagation studies. The uplink frequency beacon at 27.505 GHz (vertical polarization) will be used for power monitoring of the ACTS communications system. All beacons can be used for propagation studies.

The ACTS ground segment comprises the NASA ground station, a spacecraft control center, and experimenters' terminals. The NASA ground station, to be located at the NASA Lewis Research Center in Cleveland, Ohio, will include the master control station, a low-burst-rate terminal, and a high-burst-rate terminal. The GE satellite control center in East Windsor, New Jersey, will be linked to the NASA ground station via terrestrial voice and data circuits. The GE C-band command, ranging, and telemetry station at Carpentersville, New Jersey, will provide transfer orbit support and serve as an operations backup to the satellite control center. Additional ground terminals will be provided by ACTS experimenters.

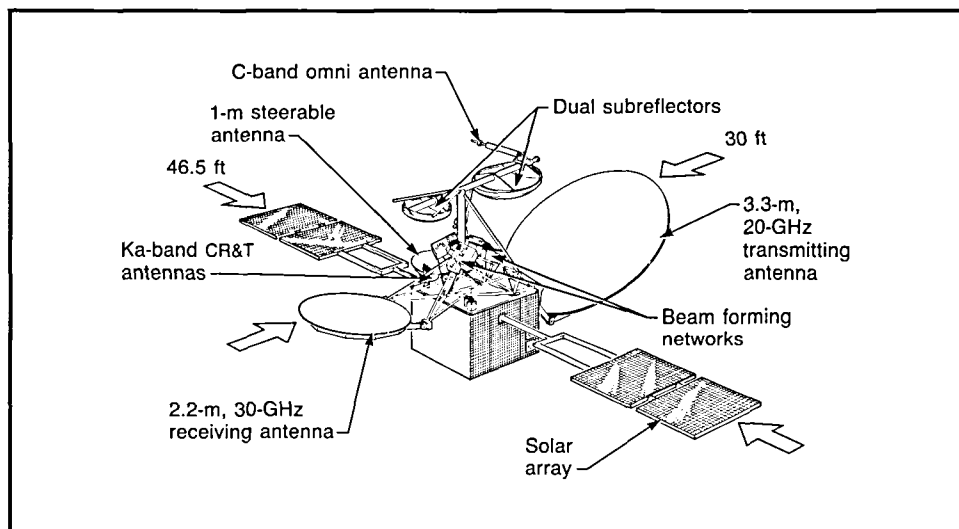


Figure 2.—Advanced Communications Technology Satellite.

The master control station will control the spacecraft, control the network, manage the experiments, and record data. It will also process and set up all traffic requests, assigning traffic channels on a demand basis by using in-band orderwire channels via the satellite.

The ACTS system, shown schematically in figure 3, has two operating modes: baseband processor and microwave switch matrix. Figure 4 illustrates their use.

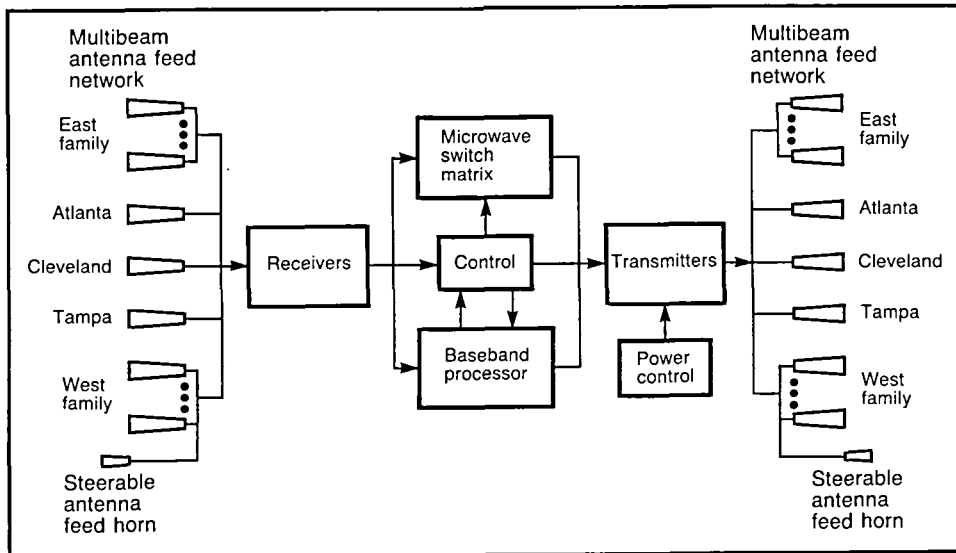


Figure 3.—ACTS system.

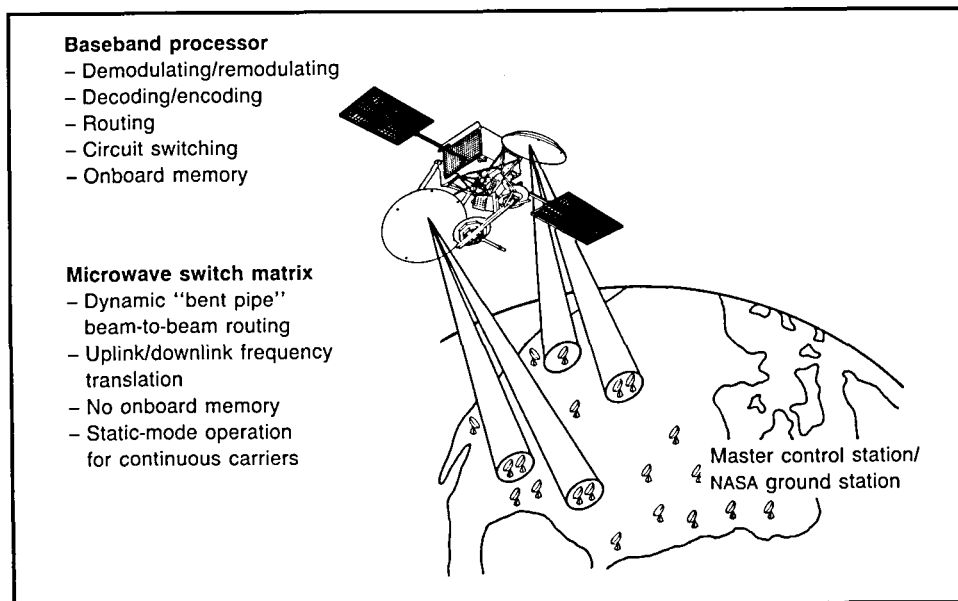


Figure 4.—ACTS switching and processing technology.

In the baseband processor operating mode the received signals are demodulated, decoded as required, routed on a circuit-switched basis by using onboard stored program control and memories, remodulated, encoded as required, and transmitted in the downlink beams. Low burst rate is a frequently used designation for this operating mode.

In the microwave switch matrix operating mode a memoryless matrix switch used in a 3×3 configuration provides dynamic beam-to-beam routing. Fixing the beam interconnections in a static mode allows additional experimental flexibility with continuous carriers. High burst rate is a frequently used designation for this operating mode.

Baseband Processor

Overview.—Introducing spot beams onboard the satellite (1) allows the use of small-aperture, low-power, economical ground terminals and (2) gives the ability to hop the beams to aggregate traffic from widely dispersed areas in a spatial demand-assigned mode. Using spot beams with beamwidths of $1/3^\circ$ or less will permit multiple frequency reuse in operational systems. A spaceborne antenna that can produce such small beams has a large aperture. Such an antenna has two beneficial effects. First, its high gain produces extremely high effective isotropic radiated power (EIRP) in each of the downlink beams from a relatively low-power amplifier onboard the satellite. Second, the same antenna also produces a very high gain-to-noise-temperature ratio, requiring low uplink EIRP from the participating ground terminals.

Hopping beams are most useful for serving areas where traffic is spread geographically and no single area has sufficient traffic to justify the use of a stationary spot beam. Beam hopping aggregates the traffic from such regions. The onboard switch permits full interconnectivity between all spots.

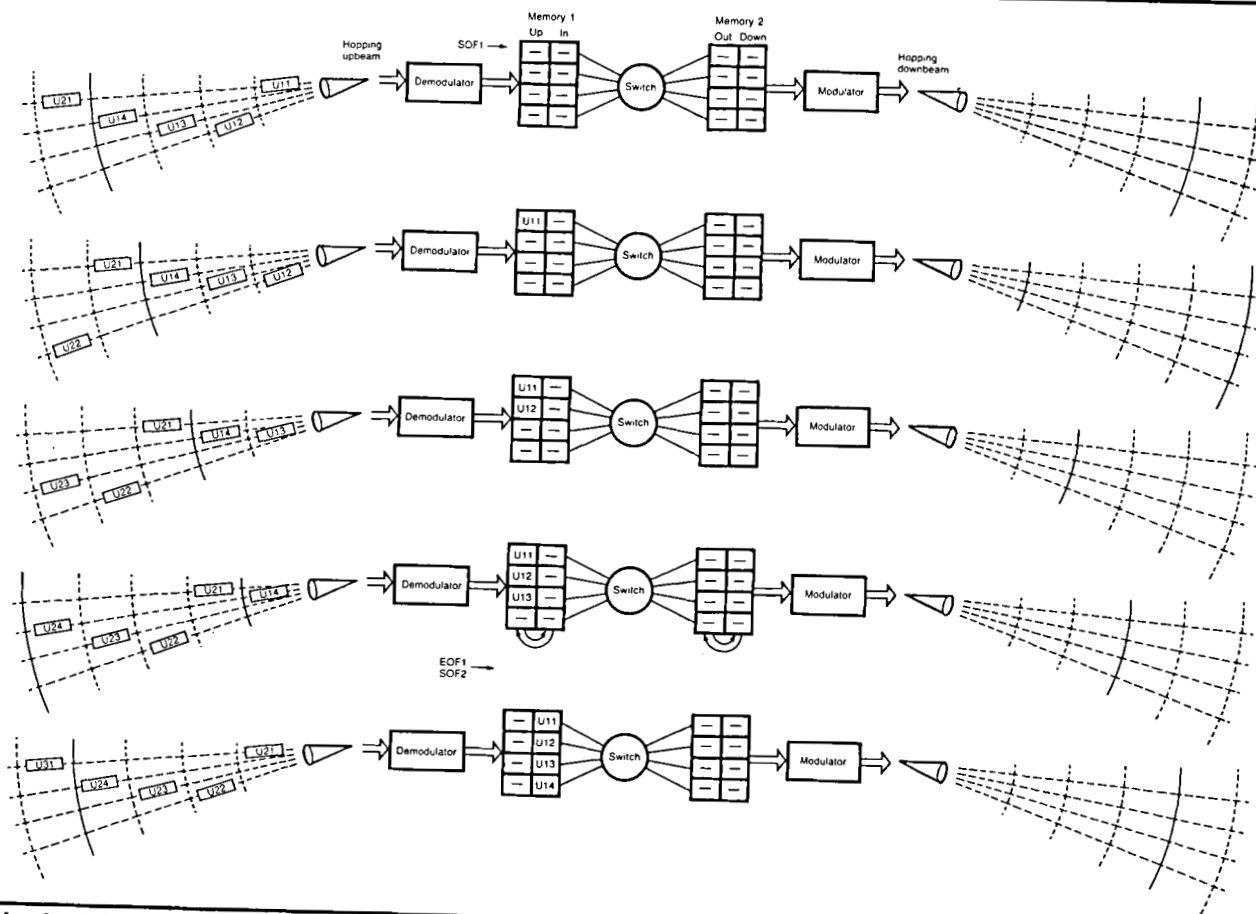
The use of symbols and bits within the baseband processor operating mode can be briefly clarified as follows: The data stream received from and sent to the user is viewed as an information bit stream. At the ground terminal this data stream, which is represented as digital voltage levels, is applied to the uplink modulator, producing a phase-modulated uplink signal. The information bits are stored on a frame-by-frame basis and then transmitted as a burst at a much higher megabit-per-second burst rate. During rain fade conditions the information bit stream is also encoded and transmitted at a lower burst rate. Burst durations, however, are increased proportionally so as to maintain a constant end-to-end information rate. By convention, ACTS uses megabits per second for uncoded transmissions and megasymbols per second for coded transmissions. At a receiver, either onboard the spacecraft or at a ground terminal, the received bursts must be demodulated and decoded (if coded when transmitted). If the original burst was uncoded, the demodulation process produces the information bit stream directly. If the original burst was coded, the data stream from the demodulator is further processed by the decoder to produce the information bit stream.

The baseband processor using baseband-switched TDMA performs three functions. After the TDMA traffic bursts coming from the ground terminals have been sampled in the beam dwells during a receiving frame (F1), it routes the contents of the individual uplink channels into the appropriate demodulators or decoders and then to the input memory of a time-space-time switching machine. During the next frame (F2) it reformats these signals into a new configuration of downlink TDMA traffic bursts. In frame F3 it transmits the reformatted traffic bursts, in the selected coded or uncoded format and with the selected data rate, to the destination stations in the appropriate downlink hopping beam dwell.

Figure 5 illustrates how the traffic bursts of the first TDMA frame to arrive at the satellite are received, reconfigured, and retransmitted during the first three frames. For simplicity the following explanation shows only one TDMA burst arriving at the satellite in each beam dwell. Several bursts per beam dwell are normally allowed. The beam dwells will also have different durations as determined by actual traffic demand and duration. Figure 5(a) shows the action during the arrival of the first TDMA frame. The onboard multibeam antenna looks in the direction of each burst and dwells there for the duration of the burst plus the "guard time" needed to account for uncertainty in burst position and the time needed to switch from beam to beam. After the first burst has been received and stored in an uplink memory, the beam then looks in the direction of the second burst, stores the second burst, looks in the direction of the third burst, stores the third burst, and so on until it has received all bursts from all directions. It repeats this operation for each newly arriving TDMA frame.

Figure 5(b) shows what happens during the second TDMA frame. Through the action of a pair of memories operating in "ping-pong" fashion from frame to frame, the bursts stored in uplink memories during the first frame are transferred to the baseband switch input memory at the end of frame 1 (EOF1). At the start of frame 2 (SOF2), the baseband switch reconfigures the uplink traffic contained in the bursts of the first frame into new groups for downlink bursts and stores these in its output memory. The output memory, which also operates two sections in ping-pong fashion, transfers the reconfigured bursts from the switch output into the downlink memory at EOF2. During this same interval the second frame to arrive is being stored in the uplink memory.

Figure 5(c) shows events occurring in the third TDMA frame, starting at SOF3. The reformatted bursts stored in the downlink memory are transmitted on the downlink beams as bursts in a TDMA frame into the destination directions by using the same beam hopping method as for the uplink beam. The downlink TDMA frame has a burst structure similar to that of the uplinks; however, the traffic channels have been reconfigured to carry a mixture of channels derived from the uplink bursts organized according to the most recent traffic demand. Of course, during this same frame interval the traffic bursts of the third TDMA frame to arrive are being stored in the uplink memory and those of the second are being reconfigured. This process continues for all arriving TDMA frames until it is changed by a change in the burst time plan.



(a) Frame 1.

Figure 5.—Baseband switching of TDMA traffic during first three frames.

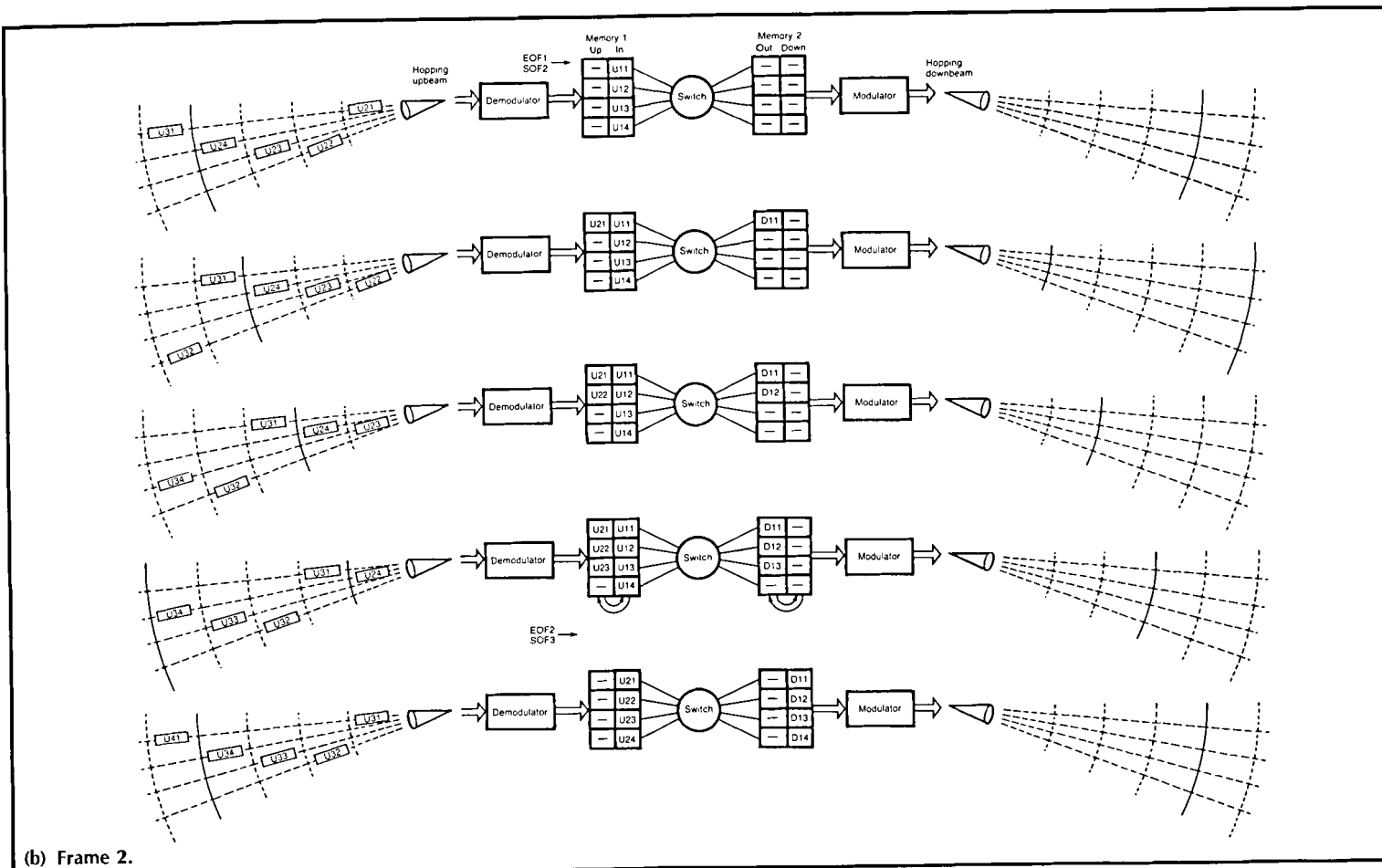


Figure 5.—Continued.

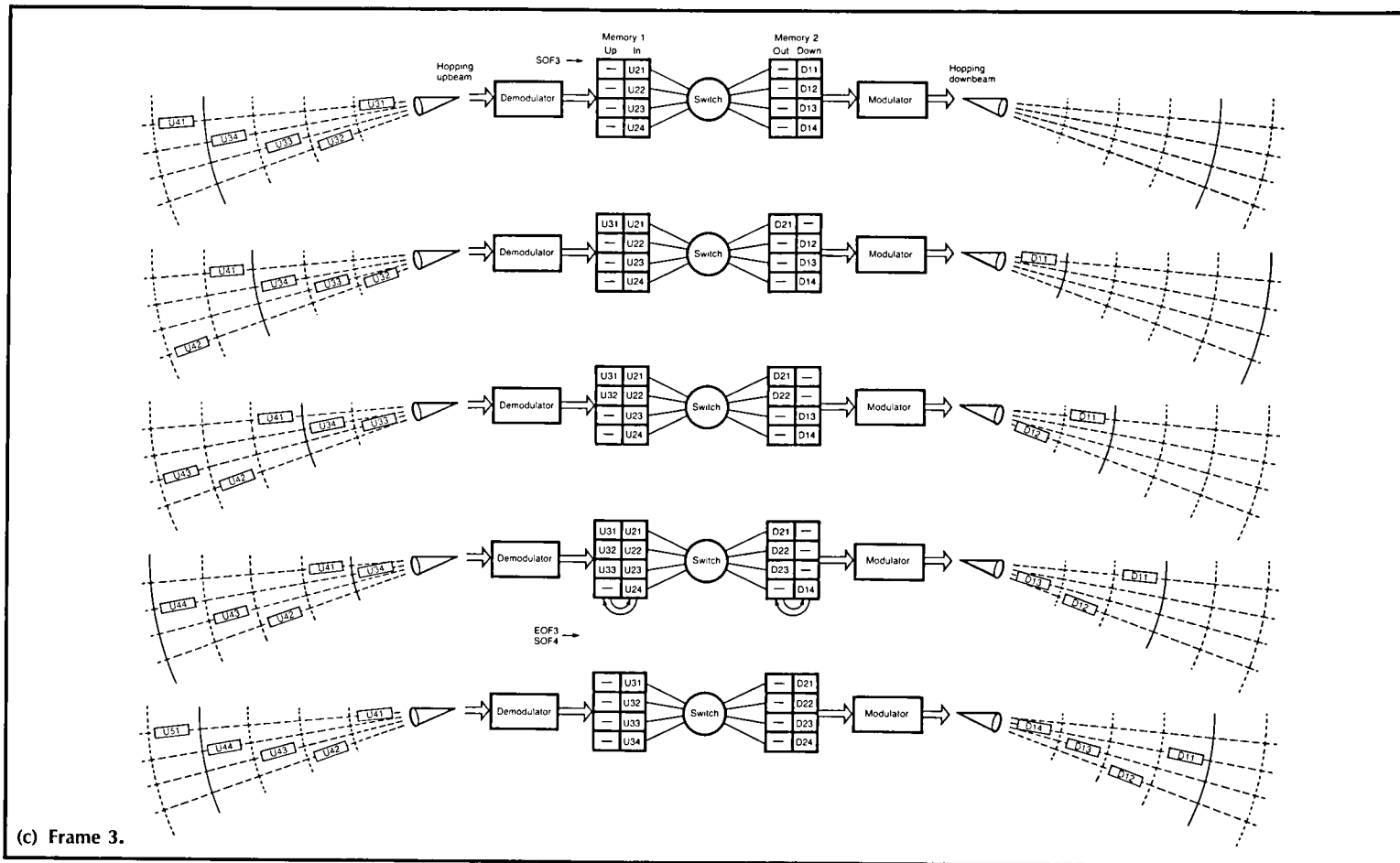


Figure 5.—Concluded.

Operating mode.—The ACTS baseband processor processes, controls, and routes all digital, voice, data, and video messages between small ground terminals located directly on a customer's premises. The baseband processor operates with two simultaneous and independent hopping beam families (both uplink and downlink) to provide flexible, demand-access communications between small ground terminals. All ground terminals of the two hopping beam families are completely interconnected in a mesh network by a single pass through the satellite. The channel frequency assignments for the two beams are identical (frequency reuse). The baseband processor operates in a TDMA format with a 1-ms timeframe. Power-efficient serial minimum shift key (SMSK) modulation is used. A unique feature of the baseband processor is that uplink and downlink multiplexing formats can be different. Uplink bursts are carried as frequency-division-multiplexed (FDM) signals with time-division multiple access (TDMA). Downlink bursts are transmitted in a pure time-division-multiplexed (TDM) mode.

Uplink and downlink transmissions are coordinated by burst time plans synchronized with the hopping spot beam dwells. The baseband processor routing is switchable on a word-by-word basis in each 1-ms timeframe, where a word is equivalent to the capacity of a 64-kilobit-per-second (kbps) message channel. Any mix of voice, data, and video messages in increments of 64 kbps can be accommodated at the terrestrial interface.

The baseband processor can be programmed to dynamically reconfigure message routing in order to accommodate traffic changes. It is controlled by the digital routing processor to be described later. Rain fade is controlled by a combination of forward error correction (FEC—convolutional encoding rate, 1/2; constraint length, 5) and two-to-one burst rate reduction. Forward error correction can be selectively applied to individual uplink or downlink channels in order to overcome localized rain fading.

A functional block diagram of the ACTS baseband processor is shown in figure 6. The major elements are two hopping beam input ports, a 3×3 routing switch, and two hopping beam output ports. The channels are functionally identical and share a common routing switch. One channel (input and output) is for the east hopping beam family; the other channel is for the west hopping beam family. The third input and output ports of the routing switch connect the digital routing processor to the hopping beams for synchronization and control.

Each input channel contains three dual-rate SMSK demodulators, input memory, and decoders. The demodulators receive intermediate-frequency (IF) inputs consisting of SMSK-modulated bursts at approximately 3.2 GHz. Uncoded (clear weather) bursts are received at 110 and 27.5 megabits per second (Mbps). Coded bursts, using forward error correction for rain fade, are received at 55 and 13.75 megasymbols per second (MSPS), respectively. Bursts are received by either a 110/55-MSPS demodulator or by two 27.5/13.75-MSPS demodulators. The two 27.5/13.75-MSPS burst rate carriers occupy the same spectral bandwidth as the 110/55-MSPS carriers. Within the 1-ms timeframe the 110/55-MSPS bursts are time multiplexed with the 27.5/13.75-MSPS bursts. The demodulator's serial outputs

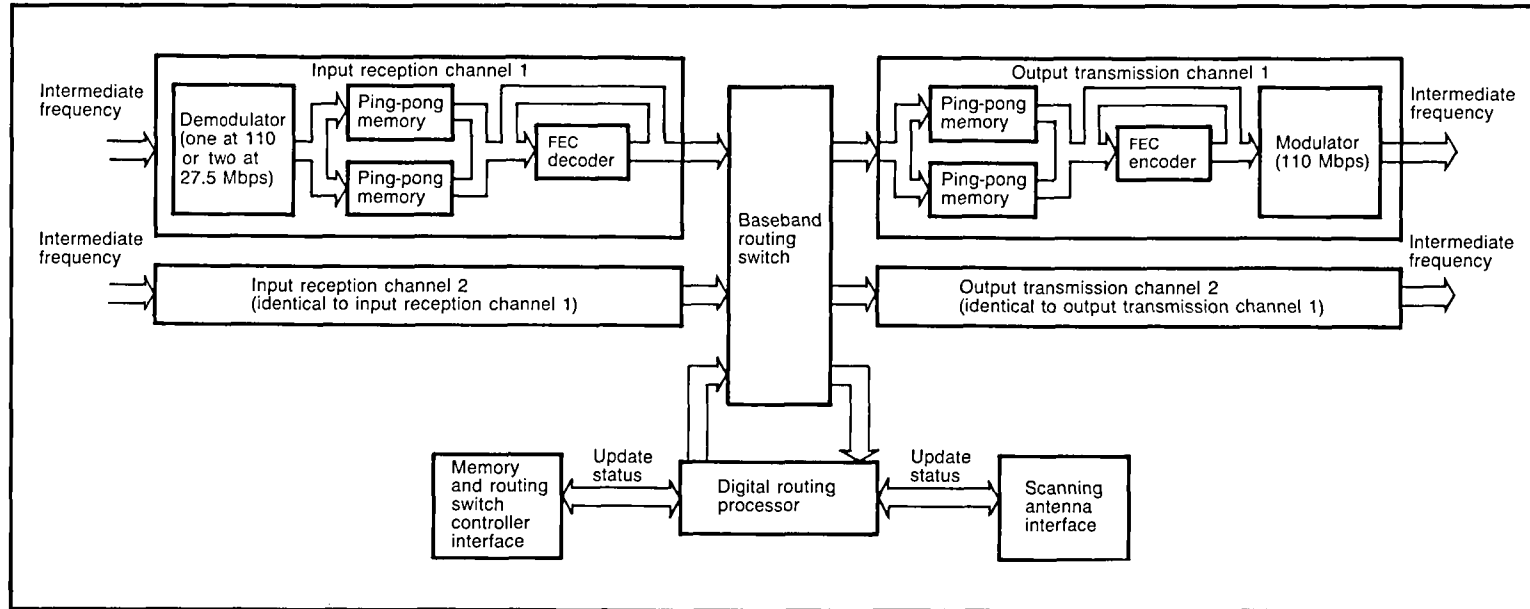


Figure 6.—Functional block diagram of ACTS baseband processor.

are converted to 64-bit data words (minimum channel capacity) and stored in an input data memory. Each channel's input memory can store a full frame (1 ms) of 110-Mbps data. The maximum baseband processor throughput is 220 Mbps at 110 Mbps/channel. Coded messages are read from the input memory and shifted through parallel convolutional decoders. The 3×3 nonblocking, high-speed routing switch receives 110-Mbps serial data from the two input channels and the digital routing processor. The data are switched to the two output channels and the digital routing processor on a 64-bit-word basis.

The output channels receive 110-Mbps serial data from the routing switch and store the data in 64-bit words in a manner similar to the input memories. Downlink data are formatted by reading the output memory contents with addresses programmed into a control memory. Downlink data not requiring coding bypass the encoder; data requiring coding are serially encoded before modulation. The uncoded downlink modulation rate is 110 Msps; the coded rate is 55 Msps organized in a TDM format.

Operation of the entire onboard baseband processor is controlled by the digital routing processor (DRP)—the onboard stored program controller. The DRP performs various command, telemetry, and control functions for the baseband processor. The contents of the DRP are programmed and dynamically modified by the NASA master control station in response to changing traffic demand. All network coordination is handled by the master control station via orderwires that are time multiplexed onto the same traffic bursts used to carry the message traffic.

Two control memories are used in the baseband processor—one on-line and the other off-line. The on-line memory, called the foreground memory, contains the current beam hopping and switch routing instructions and actually controls the baseband processor. The off-line memory, called the background memory, contains the new beam hopping and switch routing instructions and is held in readiness for execution to on-line status at the instant of reconfiguration. The off-line memory is loaded with new time plans via an uplink hopping beam TDMA burst from the master control station. When it is time to reconfigure the baseband processor to a new routing program, the control memories swap by interchanging the roles of the foreground and background memory pairs. This is performed in synchronism with changes in the traffic burst time plans throughout the entire network. Ongoing traffic is not interrupted.

The 1-ms TDMA uplink frame can dynamically accommodate various combinations of 110-Mbps uncoded bursts (55 Msps coded) and 27.5-Mbps uncoded bursts (13.75 Msps coded). Unlike the uplink frame, the downlink frame can only accommodate combinations of 110-Mbps uncoded bursts and 55-Msps coded bursts.

As previously mentioned, the baseband processor is dynamically programmable under control of the master control station. The functions of the station include (1) determining the traffic demands by polling the user terminals, (2) generating and distributing to the network TDMA traffic burst time plans and message channel assignments, (3) generating and distributing to the baseband processor

the beam hopping and message channel routing time plan, (4) performing synchronized changes in the burst, channel message routing, and hopping beam time plans.

Microwave Switch Matrix

Overview.—Satellite-switched TDMA using a microwave switch matrix is another cost-effective technique by which a multiple-beam satellite can achieve frequency reuse. The microwave switch matrix can dynamically interconnect uplink and downlink beams in accordance with any desired connectivity matrix pattern (called a switch state) for a dwell interval of programmable location and duration. A selection of beam-to-beam or broadcast connections that join single uplink beams with several downlink beams is available. A continuous sequence of switch states made up of appropriately selected patterns and dwell times, repeated each TDMA frame, controls the flow of traffic between the beams by means of the microwave switch matrix.

No onboard demodulation, storage, or message traffic rearrangement is possible with the microwave switch matrix. The traffic bursts are simply connected from a particular uplink beam to a particular downlink beam during their passage through the satellite. The traffic burst time plan, the microwave switch matrix time plan, and the uplink and downlink beam dwell pointing schedule all must be coordinated to accomplish unimpeded traffic flow between the network terminals.

Figure 7 illustrates the operation of satellite-switched TDMA with a microwave switch matrix. Three uplink beams—A, B, and C—are connected to three

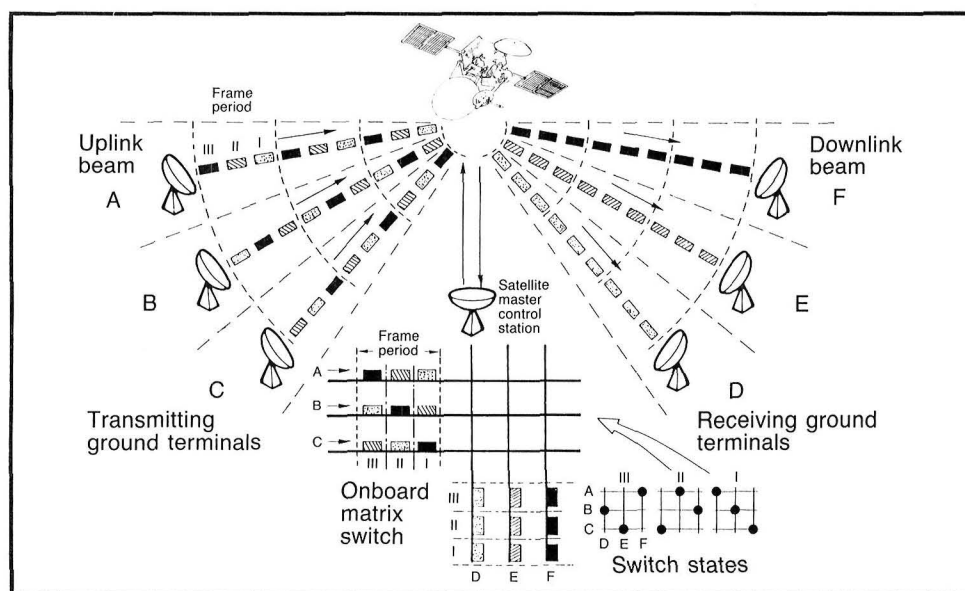


Figure 7.—Satellite-switched TDMA using microwave switch matrix.

downlink beams—D, E, and F. The onboard microwave switch matrix, which is a 3×3 matrix for this illustration, provides routing between the beams by connecting various uplink beam rows to various downlink beam columns. Each crosspoint is controlled by a memory that stores the patterns of connected and nonconnected crosspoints (switch state). A switch state will last long enough to carry the traffic load between a particular set of three uplink beams to three downlink beams. In this diagram three equal-duration switch states are shown for routing traffic in three configurations that fully connect the uplink and downlink beams. Switch state I connects A–D, B–E, and C–F, switch state II connects A–E, B–F, and C–D, and switch state III connects A–F, B–D, and C–E. These three switch states provide three equal-duration opportunities in each TDMA frame for traffic bursts, indicated by the various shaded blocks, to be routed from each uplink beam to each downlink beam. Note that (1) the traffic does not stop onboard the satellite but simply flows in real time according to the routes provided by the switch and (2) the uplink and downlink beams are fully loaded with traffic, but the traffic destined for each downlink beam occurs at different times in each uplink beam. In an operational system more than three switch state patterns would be used in each TDMA frame to optimize the traffic flow, the duration of switch states would most likely be different, and there would be many more stations in those beams with traffic bursts of different durations.

Operating mode.—ACTS employs an onboard 3×3 microwave switch matrix with planar crossbar architecture that permits all possible connections between three uplink beams and three downlink beams. (The actual hardware will be a 4×4 matrix to permit three-out-of-four redundancy.) The crosspoints use dual-gate field-effect transistors in a hybrid switch/amplifier module. The high-volume communications traffic will be dynamically interconnected on a TDMA basis. In a 900-MHz wide (1-dB bandwidth, amplitude limited) transmission channel the uplink signal will be downconverted to intermediate frequency, routed via the microwave switch matrix, and upconverted to the downlink frequency. Transmissions are planned at a nominal burst rate of 220 Msps in the SMSK modulation format for both uplink and downlink.

Switch configurations are programmable and can be changed by the master control station to optimize traffic flow. Demand assignment is controlled by two-way, in-band orderwire channels between the station and the ground terminals. The duration of each beam dwell is adjusted to provide the capacity needed to satisfy the traffic demand of the terminals residing within the dwell region. Output power control compensates for fade independently on both the uplink and the downlink. Dual-power-mode traveling-wave tubes (TWT) with saturated output power levels of 46 and 11 W will be used onboard the spacecraft.

The normal mode planned for the microwave switch matrix is satellite-switched TDMA. The switch and the multibeam antenna make possible wideband Ka-band communications to the ground terminals. The microwave switch matrix can be frozen to provide three fixed, wideband, spot-beam-to-spot-beam transmission channels in a “bent pipe” configuration. Such a static configuration will allow continuous, single- or multiple-carrier FDMA transmissions.

System Antenna Coverage



The ACTS multibeam antenna system provides electronically controlled high-gain spot beams and is a key technology to be validated as part of the ACTS flight system. The multibeam antenna system consists of separate transmitting and receiving offset Cassegrain antennas, each with a dual, gridded subreflector in a piggyback configuration. The 30-GHz receiving antenna is 2.2 m in diameter; the 20-GHz transmitting antenna is 3.3 m in diameter. The antenna diameters are scaled so that the gains and spot beam sizes are the same for both uplink and downlink beams. The expected nominal ranges of gain-to-noise-temperature ratio and effective isotropic radiated power are given in table I. The transmitting antenna's main reflector is equipped with a two-axis drive that allows vernier

TABLE I.—SUMMARY OF ACTS LINK BUDGET
[Values subject to change as design is stabilized.]

Beam	Receiving polarization ^a	Receiving	Transmitting	Spacecraft effective isotropic radiated power, dB	Spacecraft gain-to-noise-temperature ratio, dB/K
		Gain (at edge of coverage) ^b , dB			
East family					
East scan sector	Horizontal	^c 47.7	^c 46.8	59.6	17.0
Houston	↓	50.8	50.6	62.9	19.2
Kansas City		50.8	50.7	63.0	19.4
Los Angeles–San Diego		49.2	48.1	60.4	17.1
Miami		50.6	50.2	62.6	18.9
Nashville–Huntsville		50.9	50.8	63.0	20.0
Seattle–Portland		49.1	48.3	60.6	17.0
West family					
West scan sector	Vertical	^c 46.1	^c 47.1	59.4	16.0
Dallas	↓	49.2	50.6	62.6	18.0
Denver		48.9	50.2	62.3	17.7
Memphis		49.5	50.9	63.0	18.1
New Orleans		49.3	50.8	63.0	18.1
Phoenix		48.5	48.8	61.0	17.5
San Francisco		48.1	46.1	57.9	16.8
White Sands		48.9	49.8	62.1	17.7
Steerable		----	----	55.6	----
Stationary beams					
Cleveland	Horizontal	50.5	51.3	^d 57.8/64.0	20.1
Atlanta	Vertical	50.0	51.4	^d 57.8/64.0	19.5
Tampa	Vertical	50.0	51.0	^d 57.4/63.7	19.8

^aTransmitting polarization is orthogonal to receiving polarization.

^bEdge of coverage for spot beams is defined as 0.27° beamwidth and is nominally 2 dB less than peak gain.

^cMinimum scan sector gain.

^dRatio of low-power to high-power modes.

adjustments of the boresight to align it with the receiving antenna. The front subreflector is gridded to pass one sense of polarization and reflect the orthogonal polarization. The back subreflector is solid and reflects the polarization transmitted by the front subreflector. The focal axes of the two subreflectors are tilted with respect to the main reflector's plane of symmetry so that the two orthogonally polarized feed assemblies (east family and west family) can be placed side by side without mechanical interference. Compact, conical, multiflare horns formed by three flared waveguide sections are used for the fixed and isolated spot horns. To meet the stringent spacecraft pointing requirements (0.025°), the receiving antenna will have a monopulse tracking capability associated with the Cleveland fixed beam.

ACTS will employ two hopping spot beam families and three fixed beams for both transmitted and received signals (fig. 3). The beams will provide the coverage shown in figure 8. The hopping beams will be programmed to visit only those areas with traffic for any given experiment scenario. The hopping beams, designed primarily for the baseband processor operating mode, consist of two independent uplink and downlink beams (four beams total) providing simultaneous coverage at the same frequency. The half-power beamwidth of these spot beams is approximately 0.33° , covering roughly a 135-mile diameter. One uplink-downlink beam combination covers the east hopping beam family and the other covers the west hopping beam family. The east family consists of (1) an east scan sector—contiguous areas in the eastern portion of the United States and (2) six isolated spots covering Miami, Nashville-Huntsville, Houston, Kansas City, Seattle-Portland, and Los Angeles-San Diego. The west family

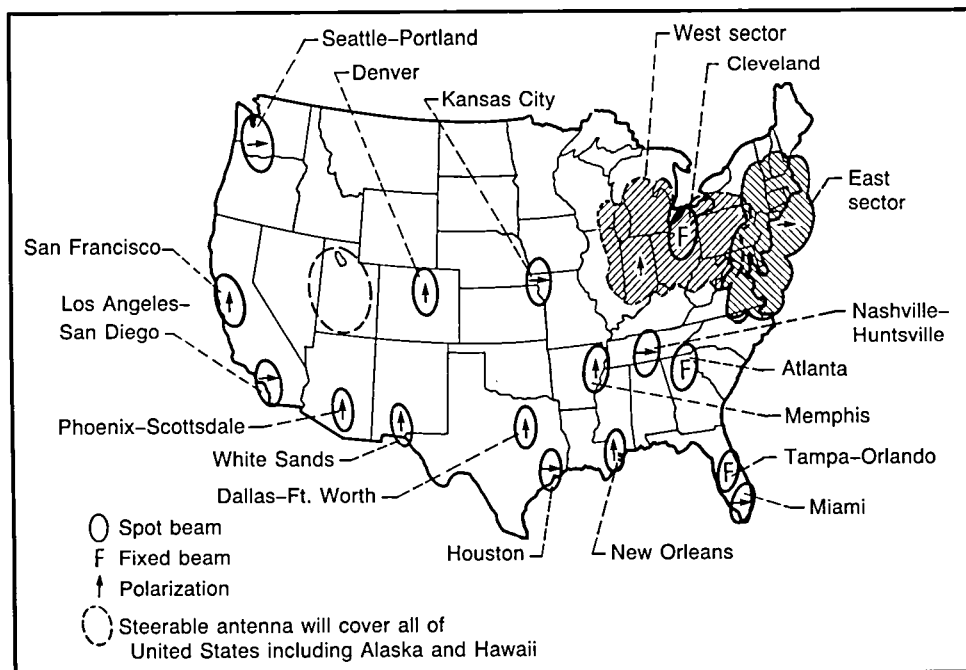


Figure 8.—ACTS multibeam antenna coverage. (ACTS at 100° west longitude.)

consists of (1) a west scan sector—contiguous areas in the midwestern portion of the United States and (2) seven isolated spots covering Memphis, New Orleans, Dallas, White Sands, Phoenix, San Francisco, and Denver. In addition, the west beam family includes a separate steerable antenna for coverage to Alaska and Hawaii as well as any location within the ACTS hemispherical field of view.

The separate 1-m-diameter steerable antenna consists of a single offset reflector fed by a diplexed, corrugated horn for both transmitted and received signals. The ground coverage spot diameter for the half-power beamwidth at uplink frequency (29 GHz) is approximately 290 miles. Actuator electronics will mechanically “steer” this antenna in 0.015° increments over a range of $\pm 10^\circ$ in two axes. Scan rates of 1° per minute will be sufficient to track the shuttle or any low-Earth-orbiting satellite within the ACTS field of view. The gain of the steerable antenna will be lower than that of the main transmitting and receiving reflector because of its smaller size.

The multibeam antenna will also provide three fixed beams designed primarily for the microwave switch matrix operating mode. The beams will be pointed at Cleveland, Atlanta, and Tampa. The uplink and downlink signals of each fixed beam are orthogonally polarized. In addition, the Cleveland horn is orthogonally polarized to the Atlanta and Tampa horns. In the microwave switch matrix operating mode either or both of the east and west hopping beams can be substituted for one or two of the three fixed beams. These can be operated in either a stationary mode or a limited hopping beam mode. For TDMA operations a control beam must always dwell on Cleveland during some part of the 1-ms timeframe in order to maintain synchronism between the ground and flight segments.

A microwave schematic for the east-family beam forming network is shown in figure 9. This schematic is accurate for both transmitting and receiving. The major microwave components in the beam forming network are the ferrite switches, the interconnecting waveguide, the power divider or combiner (depending on the direction of the transmission), and the antenna horns. A signal is input to the first switch in the transmitting east-family beam forming network. The switch is used to switch between the east scan array and the six isolated spot beams. If the scan array is chosen, the signal is then equally divided (both phase and amplitude) into three signals—one for each branch of the scan array. The three signals are appropriately switched to three adjacent horns of the 12-horn east scan array in order to form a spot beam. These three adjacent horns form a “triplet” and are mechanically arranged in an equilateral triangular lattice within the beam forming network. By switching the power distribution from one horn to its adjacent horn, while maintaining a triangular triplet configuration, the peak of the spot beam can be hopped from one position to another throughout the prescribed coverage area. Switch time is on the order of 800 ns. Triplets will be energized to form beams only for those areas with traffic. If the isolated scan spots are chosen, the beam forming network is configured to excite one isolated spot at a time and can be switched to hop from one traffic spot to another. The receiving east-family beam forming network operates similarly, except that the signal path is reversed.

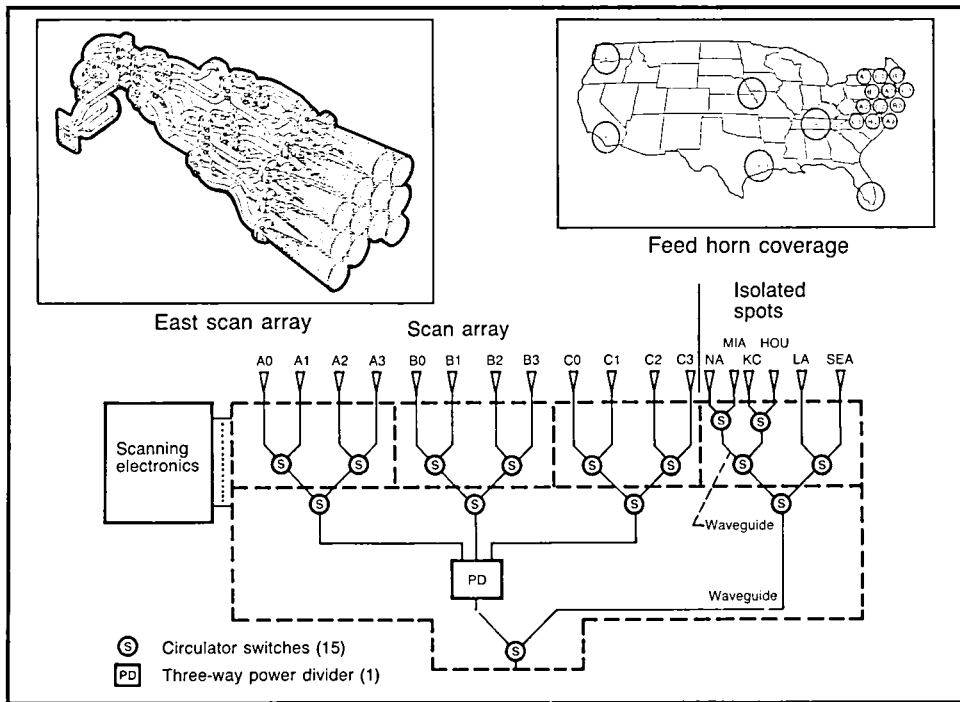


Figure 9.—Schematic of ACTS multibeam antenna east-family beam forming network.

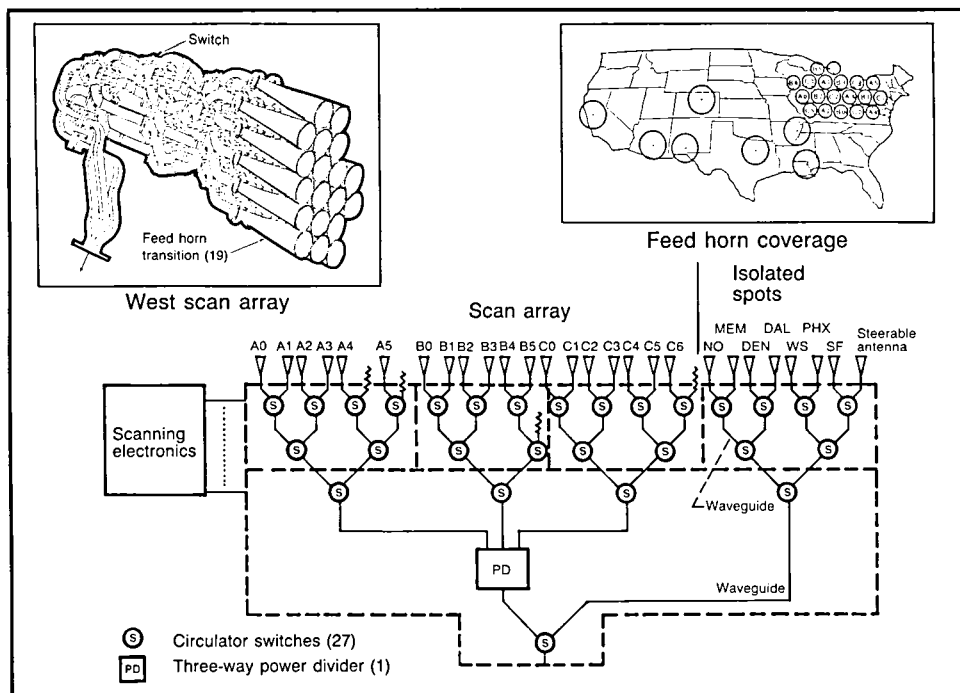


Figure 10.—Schematic of ACTS multibeam antenna west-family beam forming network.

Figure 10 presents a microwave schematic of the west-family beam forming network. Both the transmitting and receiving operations are similar to those for the east family. The west-family transmitted signals are orthogonally polarized to the west-family received signals and the east-family transmitting signals. The west scan array comprises 19 horns. Seven isolated spots are used in addition to the steerable antenna, which is switched as one of the isolated spots.

The scanning patterns of both the east- and west-family beam forming networks are electronically controlled by spacecraft onboard memories that are programmed by the master control station according to traffic demands. As the four beams (east transmitting, west transmitting, east receiving, and west receiving) independently and simultaneously hop from spot to spot, they need to stop at only those locations having communications needs at the moment and only long enough to satisfy those needs. Therefore the hopping beams provide dynamic coverage in response to fluctuating user demands.

The ground coverage patterns of the ACTS multibeam and steerable antennas are flexible enough to accommodate and interconnect experiments in various network configurations.

Baseband Processor Ground Segment

The previous discussion gave an overview of ACTS operation. A more detailed description of the baseband processor operating mode is presented here.

Baseband-switched TDMA.—In the baseband processor operating mode a low-burst-rate ground terminal enters the system by first synchronizing its receiving side to a receiving acquisition burst (RAB) specifically addressed to the acquiring terminal and sent by the onboard baseband processor under the control of the master control station. Figure 11 presents the uplink TDMA frame structure; and figure 12, the downlink frame structure. This burst contains range correction information that permits the acquiring terminal to locate its own transmitting acquisition burst (TAB) so that it arrives at the satellite near its scheduled arrival

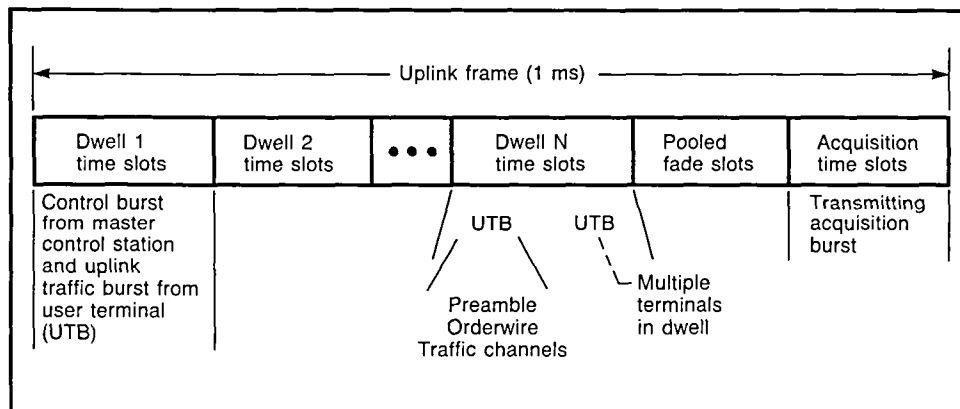


Figure 11.—Structure of uplink baseband processor TDMA frame.

time in the TDMA frame. The range correction is given by a tracking error word that informs the acquiring terminal whether its burst arrived at the satellite within a targeted 60-ns window and whether it arrived early or late relative to the instant of correlation at the center of the window. It also identifies the number of the burst that accomplished the correlation.

The acquiring terminal scans its transmitting acquisition burst by advancing it in steps of eight-symbol periods every four frames until it receives a receiving acquisition burst with an early or late condition in the tracking error word that indicates successful correlation at the satellite. This same RAB also identifies the TAB number responsible for the correlation. Subtracting that TAB number from the current TAB number determines the backup timing correction needed to compensate for downlink transmission delay between the satellite and the ground terminal.

Synchronization is maintained by correcting the TAB position in accordance with the early or late indications in the tracking error word. Once this part of the acquisition procedure is completed, the ground terminal sends an acquisition-accomplished message to the master control station in the inbound orderwire contained in its TAB. The master control station next instructs the acquiring terminal to transfer its receiving-side synchronization to a reference burst that is transmitted at the start of the beam dwell directed to the terminal's geographic location and that identifies the timing locations for its transmitting and receiving traffic bursts. This transfer is accomplished between TDMA frames with no interruption to synchronization or traffic flow continuity by a synchronous change in the burst time plan.

The ground terminal is now fully acquired and synchronized and ready to start carrying traffic. In its traffic burst the terminal has an inbound orderwire in which it can send messages to the master control station requesting traffic routing and meteorological conditions needed for rain fade control. In the reference burst the terminal continues to receive both its tracking error word from the baseband

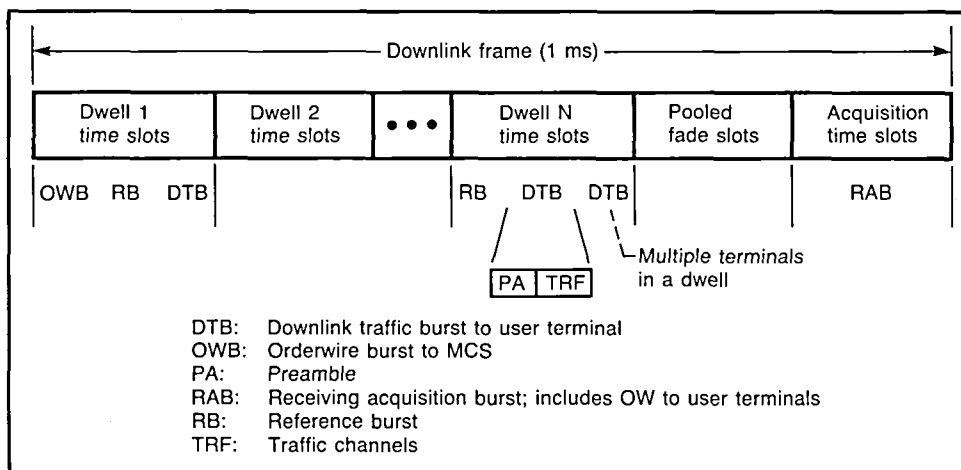


Figure 12.—Structure of downlink baseband processor TDMA frame.

processor and an outbound orderwire on which messages are received from the master control station relating to burst time plan modifications, application of coding, and execution of synchronous changes in the burst time plan.

Terminals.—The baseband processor system can operate with a VSAT LBR-1 or LBR-2 ground terminal that has a 2.4-m-diameter antenna. With uncoded operation at a transmission burst rate of 110 Mbps the LBR satellite uplink gain-to-noise-temperature ratio of 16 dB/K makes it possible to achieve excellent uplink signal-to-noise ratios over the ACTS coverage area with 40 W of ground terminal high-power-amplifier output and the 2.4-m antenna. An alternative 27.5-Mbps uplink burst rate permits operations with a power output of 10 W. A rate-1/2 coded mode operating at uplink throughput rates of 27.5 and 6.912 Mbps improves the link margin by 10 dB in each case. This improvement may be used to combat uplink rain fade or to reduce the ground terminal EIRP and hence the high-power-amplifier power requirement for clear-sky operation. A similar 10-dB augmented margin operating mode is available on the downlink, resulting in a downlink carrier bit rate of 27.5 Mbps and allowing for rate-1/2 forward error correction.

Microwave Switch Matrix Ground Segment

Satellite-switched TDMA.—The microwave switch matrix operating mode onboard ACTS is supported by a 4×4 microwave switch matrix that is arranged to dynamically interconnect any three uplink beams to any three downlink beams with an interconnection bandwidth of approximately 900 MHz in each path. The additional switch path provides redundancy. The three uplink beams and three downlink beams can be selected from the three fixed uplink and downlink beams, the east or west scanning beams, or the steerable beam. The signal path is only frequency converted to a 3.2-GHz intermediate frequency and is not transformed to baseband. Consequently the uplink beams are simply rerouted to the downlink beams according to the connections of the microwave switch matrix at the time of passage through the matrix. The microwave switch matrix can be operated in a dynamic or static mode. Its connections are controlled by an onboard memory that stores a sequence of switch connection patterns. Each pattern's connections and associated duration is referred to as a switch state. In the dynamic operating mode the sequence of stored switch states is played out during a TDMA frame; each switch state is invoked for its designated duration. The switch states are selected to accommodate the traffic flow between the three uplink and three downlink beams. In the static operating mode the microwave switch matrix is frozen permanently in one of the switch states. For the 3×3 matrix operation there are six single-point, beam-to-beam connection patterns and 12 broadcast connections that can be used to direct traffic and reference burst transmissions for dynamic operation or continuous carriers for static operation.

To use the microwave switch matrix in the dynamic operating mode, ground terminals must properly synchronize their burst transmissions to arrive at the satellite at the proper time in the frame so that they pass through the matrix in

their assigned epochs of the appropriate switch state. To do this, the network of ground terminals must be synchronized to the switch state pattern of the onboard microwave switch matrix. This is accomplished by means of a reference station, which may be the NASA ground station. The reference station sends a special burst called the metering burst through the satellite switch, which is programmed to loop the burst back to a beam containing the originating reference station. This metering burst is designed to make it easy for the originating reference station to measure its location in the loop-back switch state with high time precision. The originating reference station continuously corrects the transmitting side timing of the metering burst to maintain the burst location at the satellite. When this timing loop is closed through a second-order predictor, the microwave switch matrix and the reference station are precisely synchronized.

Next, the reference station sends reference synchronization bursts containing the network control orderwire to the various beams; the ground terminals then synchronize their receiving sides to these reference bursts. To enter a transmitting burst into the microwave switch matrix network, each ground terminal must be given an entry phase correction so that it can locate a reference burst in a designated switch state that loops back to the ground terminal. Once this is accomplished, each ground terminal maintains the position of the reference burst in the frame by conventional loop-back synchronization, adjusting its location to be at a fixed time offset relative to the reference burst. Traffic bursts can now be located by offsets relative to the reference burst. The traffic burst positions are distributed to all network terminals by time plans sent from the central reference station via the orderwire. The satellite switch-state time plan must also be sent to the satellite. The traffic burst time plan must be synchronized so that the entire plan occurs on the same TDMA frame boundary at the satellite in order to prevent interruption of the ongoing traffic. This is accomplished by a change in the two time plans, the traffic burst time plan and the satellite switch-state time plan, both of which must be synchronized among all network terminals.

Terminals.—The microwave switch matrix is designed to carry a single 220-Mbps SMSK carrier in each of the spacecraft's three transponders. NASA will conduct tests on the microwave switch matrix using a ground terminal with a 4.7-m-diameter 50-W antenna and 110-Mbps SMSK modulators. Each transponder has a 900-MHz bandwidth and is preceded by amplitude limiters that saturate on the normal thermal noise. These transponders will also be able to carry lower-bit-rate single carriers while using much smaller ground terminal antennas and power. The action of the amplitude limiters does cause much lower high-power-amplifier signal suppression, but nonetheless it is still possible to use the transponders to repeat low-level signals. For example, a rate-1/2, coded, 5-Mbps quadrature-phase-shift-keyed (QPSK) carrier can be supported with a 5-dB clear-sky margin by using ground terminals equipped with a 2.4-m-diameter antenna and a 1-W high-power amplifier. It is also possible to support a multiplicity of single-channel-per-carrier FDMA channels with very low high-power-amplifier power output (less than 1 W) and with antennas smaller than 2.4 m. Studies are under way to precisely quantify the number of channels and the required power.

Experiment Opportunities



The ACTS system provides many opportunities for experimenters to explore new communications disciplines needed for the control and operation of a "switch in the sky" able to route telephone calls on demand between small ground terminals distributed over the entire continental United States. The ACTS capability will stimulate studies and support experimental verification of network control algorithms to optimally exploit the full demand assignment potential of its traffic switching and beam hopping functions. ACTS will be a test bed for exploring advanced Ka-band and onboard digital technologies. This will accelerate the commercial development of key components needed to build low-cost ground terminals and the associated space segment to operate in this new frequency band. The switch in the sky and hopping spot beams can be used to demonstrate new rooftop-to-rooftop business communications services with ground terminals that can be realistically expected to be inexpensive. The same capability can be used to demonstrate the long-distance transmission of telephone trunks directly between widely separated terrestrial telephone switching machines. Such a capability can be an attractive way for satellite service to fill in the gaps where terrestrial optical fiber is not economical in domestic or international applications. The capability to operate with terminals as small as 1.8 m will be of great value for emergency communications and for applications in remote regions and on mobile platforms. A high-EIRP transmission capability in space coupled with a ready capability to communicate data will be an excellent means to synoptically collect user-oriented system performance measurements and propagation data at the Ka-band frequencies of 20 and 30 GHz.

In the following sections suggestions for experiments are presented. These suggestions are categorized as

- (1) Network control—pertaining to the control of traffic in the high- and low-burst-rate ACTS systems
- (2) Telecommunications—pertaining to experiments that will demonstrate public switched telephone network and business communications applications
- (3) System—pertaining to experiments that will demonstrate ACTS system operations
- (4) Scientific—pertaining to studies and experiments that will gain new knowledge in communications disciplines, devices, and propagation phenomena.

Network Control Experiments

Baseband processor network control protocol.—The ACTS baseband processor system provides a unique combination of onboard channel switching, beam hopping, and TDMA burst time plan structures on the uplinks and downlinks that must be properly managed to achieve optimum demand-assigned operation. The management system must continuously accept traffic demands from all the ground terminals for individual voice calls or for blocks of data. It must then

rearrange its current traffic burst time plan and its onboard switch routing and hopping beam dwell time plan to satisfy new traffic demands. It must do this in a way that efficiently uses system capacity. This requires that algorithms for rapidly generating current assignments be developed so that call setup time does not become excessively long. Algorithms based on combinatorial searching such as Greedy and bin packing are currently in use, but these are not likely to be fully satisfactory in terms of traffic fill optimization and speed of fulfillment. The algorithms devised could be tested by using master control station computers or interfacing a separate computer containing the algorithm into the ground terminal and digital routing processor control network.

Microwave switch matrix hopping beam network control.—In the microwave switch matrix hopping beam operating mode the 3×3 microwave switch matrix is used to interconnect the hopping beams. No onboard demodulation, storage, or traffic rearrangement is possible. The traffic bursts are simply connected from a particular upbeam to a particular downbeam as they pass through the satellite. Onboard implementation is simpler but poses a more difficult traffic management problem. The traffic burst time plan, the microwave switch matrix time plan, and the beam dwell pointing schedule must be coordinated to accomplish unimpeded traffic flow between the network terminals. Also the problem of providing reference bursts in the beam dwells becomes more formidable. The development of traffic routing algorithms for this type of operation is equally challenging as well as important to optimizing a system for fill efficiency and time of response. The facilities of the master control station and the NASA ground station can be used to support experimental control concepts for demonstrating this type of operation.

Use of adaptive coding in baseband processor network.—When a signal fade of sufficient magnitude occurs on an uplink of the baseband processor system, it will cause the application of both a two-to-one symbol rate reduction and a rate-1/2 forward error correction coding process, thus reducing the information rate of the communications channels by four. A similar fade on the downlink will cause the same action to take place on the satellite for the ground terminal suffering the fade. This capability is unique to ACTS and poses an opportunity to develop control techniques for using it in a harmonious way that minimizes the reserve capacity in the timeframe needed to carry the four-to-one expansion in transmission capacity. These control techniques must also not disrupt the ongoing traffic. The basis of the concept is that at any given time the need for coding exists on only a small fraction of the channels. Thus a small fraction of the timeframe capacity is set aside, ready to be tapped when needed. When the need arises, this capacity is assigned to the traffic bursts originating from or destined to the ground terminal experiencing the fade. To do this, the traffic burst time plan of the ground terminal experiencing the fade as well as the related beam dwell time plan and the onboard switching time plan need to be modified. The action can ripple throughout the time plans for the entire system as other traffic bursts are modified to accommodate the additional capacity needed by the faded terminal. This is obviously a complicated problem that will have to undergo several iterations of development. The basic ACTS system is equipped with the

control tools needed to do all the maneuvering, and some algorithms are being developed to provide a capability in the initial operating configuration. However, there is expected to be plenty of room for improvement, and experimenters are invited to explore unique solutions by using the ACTS facilities and any additional facilities they might wish to bring.

Network clock dissemination.—A property inherent in a system using a periodic frame such as the TDMA of the ACTS low-burst-rate system is the networkwide distribution of a highly accurate clock to all network ground terminals and hence to any location in the satellite's coverage area. This property can be valuable in operating a widely distributed synchronous digital network. ACTS supplies an excellent opportunity to experimentally evaluate this potential.

The timing at all terminals of the ACTS network is determined by the clock onboard the satellite, which is in turn controlled by comparison with a high-precision cesium beam clock on the ground. Thus the clock onboard the satellite reflects the accuracy of the ground clock, and hence the timing may be recovered at all network ground terminals. Special provision has been made on the link controlling the onboard clock to eliminate the influence of satellite motion so that the onboard clock is Doppler free.

Similarly the influence of satellite motion can be eliminated on the links to the ground terminals by performing ground terminal clock corrections at a nominal accuracy of 10^{-9} or 10^{-10} s. One method of accomplishing this is by sampling the satellite clock with sidereal day periodicity. It is well known that periodic sampling of a cyclic function cancels the cyclic variation. However, this method is subject to the short-term drift inherent in the ground terminal clock, 10^{-9} or 10^{-10} s for the example given above. Another method is to use a satellite range predictor to eliminate the range variation. The recovered accuracy will then be determined by the accuracy of the predictor and should be better than that achieved by the sidereal day sampling method.

Telecommunications Experiments

VSAT's using baseband processor system.—Very small-aperture ground terminals equipped with 2.4-m-diameter antennas, called LBR-1 and LBR-2, can be operated in the baseband processor TDMA system. LBR-1 stations normally use uncoded uplink and downlink burst transmission rates of 110 Mbps (throughput rate of 110 Mbps per baseband processor channel). In faded operation either or both the uplink or downlink burst transmission rates can be coded at 55 Msps (throughput rate of 27.5 Mbps per baseband processor channel). LBR-2 stations normally use an uncoded uplink burst transmission rate of 27.5 Mbps (throughput rate of 27.5 Mbps per baseband processor channel) and a downlink uncoded burst transmission rate of 110 Mbps (throughput rate of 110 Mbps per baseband processor channel). In faded operation either or both the uplink or downlink burst trans-

mission rates can be coded at 13.75 Msps (throughput rate of 6.875 Mbps per baseband processor channel). Using the parameters given in table II yields a nominal fade margin of 10 dB for both LBR-1 and LBR-2 when coding is applied. This is in addition to a nominal clear-sky fade margin of 5 dB. All margins are referenced to a bit error rate of 5×10^{-7} .

An alternative that permits operation at reduced high-power-amplifier power at the sacrifice of ensuring a link during a heavy rain fade is to use coded operation under the clear-sky condition in which there is no allowance for fade and a 5-dB uplink margin. This would result in a 10-dB reduction in the high-power-amplifier power requirements. Thus, for example, a station equipped with a 2.4-m-diameter antenna could operate with 1 W of high-power-amplifier output power, but only under clear-sky uplink conditions. Such operation could be used for demonstrations when this restriction can be tolerated. Downlink operation is not changed by invoking this choice on the uplink, and the downlink still has the full measure of rain fade allowance. Under coded operation, however, the baseband processor throughput is limited to 6.3 Msps per channel or beam.

On the downlink, operation with a 2.4-m-diameter ground terminal antenna results in a total margin of 6 dB for uncoded operation (110-Mbps throughput) and a total margin of 15 dB for coded operation (27.5-Msps throughput) assuming a satellite EIRP of 60 dBW in both cases and a gain-to-noise-temperature ratio of 27.7 dB/K.

TABLE II.—TYPES OF ACTS EXPERIMENTER TERMINALS

	Very small-aperture terminals			NASA Lewis link evaluation terminal
	LBR-1	LBR-2	HBR	
Antenna diameter, m	2.4	2.4	2.4	4.7
High-power-amplifier power, W	40	10	10	50
Uplink burst rate, Mbps	110/55	27.5/13.8	20-40	110
Downlink burst rate, Mbps	110/55	110/55	20-40	110
Modulation type	Serial minimum shift key		To be determined End-to-end coding	Serial minimum shift key Power control
Rain compensation type	Adaptive forward error correction			
Satellite switching mode	Baseband processor		Microwave switch matrix	
Access to satellite	Time division using demand-assigned multiple access			Static
Throughput capacity (nominal)	T-1 ^a	Multiple T-1	Less than burst rate	50 Mbps

^aStandard digital telephone rate of 1.544 Mbps, which supports twenty-four 64-kbps telephone channels.

All numbers appearing in this discussion may be subject to change as design parameters are further stabilized.

VSAT's using microwave switch matrix system.—Small VSAT's operating in the static beams of the microwave switch matrix system offer an opportunity for experimenters with limited budgets to perform experiments with ACTS. Small VSAT's equipped with 1.2- or 1.8-m-diameter antennas can operate in continuous single- or multiple-carrier-per-transponder FDMA fashion by using the spot beams in conjunction with the onboard microwave switch matrix set to a static connection. Any end-to-end or loop-back static connection of the three beams controlled by the matrix switch can be selected via ground control to meet the needs of experimenters. This operation option can support experiments involving small, low-power, low-cost, rooftop-to-rooftop terminals for business applications, multinode-to-hub and hub-to-multinode VSAT communications networking within the coverage confines of the multiple spot beams used, experiments to evaluate the performance of various modulation and coding techniques, and experiments to explore the distortion impairments on single- and multiple-carrier-per-transponder operation through the wideband, hard-limiting transponders used in the microwave switch matrix system.

Single-carrier-per-transponder operation: For single-carrier operation table III gives tentative transmission bit rates that can be supported at an error rate of 1×10^{-6} or less with rate-1/2 coding between 1.2- and 1.8-m-diameter antennas for various high-power-amplifier power outputs with a 5-dB margin. Current studies may modify these values slightly. This table illustrates that information bit rates sufficient to demonstrate a wide variety of service applications, demonstrations, and experiments can be supported by ACTS with ground terminals that have modest antenna size and low power requirements.

Single-carrier-per-transponder operation can be employed on either a continuous carrier basis between two ground terminals in different beams or on a TDM basis between many other terminals using synchronized TDMA or random access (either ALOHA or slotted ALOHA). How these TDMA options can be accomplished is described later in this section.

TABLE III.—TRANSMISSION BIT RATE
[Microwave switch matrix static mode.]

High-power- amplifier power, W	Antenna size, m	
	1.2	1.8
	Transmission bit rate, Mbps	
0.1	0.3	0.78
1	3.3	7.8
10	29.5	67.6
20	51.2	117.4
50	91.5	203.4

Multiple-carrier-per-transponder operation: As indicated previously the transponders used in the microwave switch matrix contain limiters that saturate, on the 900-MHz bandwidth, thermal noise presented to their inputs. Small signal operation in the static microwave switch matrix mode is under study to determine precisely how many low-power carriers can be supported within the bit error rate requirement specified for the system (5×10^{-7}). It is estimated that each transponder can support a maximum of 100 low-bit-rate carriers carrying rates ranging from a few thousand to several hundred thousand bits per second. VSAT's equipped with antennas as small as 1.2 m in diameter and high-power amplifiers with a power output of a few hundred milliwatts should be feasible. More precise values for the number of carriers, the ground terminal antenna diameter, and the power requirements will be obtained from this study. The opportunity obviously exists for supporting numerous applications, demonstrations, and experiments by using ground terminals with small antennas and very low power requirements operating at low bit rates.

Business communications.—The capability of ACTS to provide communications links on demand makes it ideal to serve the internal communications needs of private business. The ACTS baseband processor system can operate with its nominal 2.4-m-diameter VSAT ground terminal to rapidly provide customer premises links for any desired service. Furthermore its capability to demand assign the space segment capacity permits a service to be established from a capacity shared among the company's corporate services and used precisely when it is needed. This sharing of pooled capacity accomplishes great economies that could significantly reduce the cost of telecommunications services. A company thus would have total control over its telecommunications resources, a fact that could avoid long delays in service availability and be more economical than similar services that use conventional terrestrial links.

Typical examples of the corporate business services that can be supported with ACTS are

- (1) Low-bit-rate digital links at 2.4, 4.8, 9.6, and 19.2 kbps for computer communications, digital facsimile, and data communications
- (2) Medium-bit-rate digital links at 56 and 64 kbps for computer communications, data base transfer, high-speed facsimile, low-bit-rate video teleconferencing, and full National Television Standards Code quality freeze-frame television
- (3) High-bit-rate digital links at 265, 512, 768, and 1536/1544 kbps for digital video conferencing at various quality levels
- (4) Demand-assigned multiple access voice links at 64 and 32 kbps to interconnect the private branch exchanges of a company's communications system
- (5) A corporate business communications network center for controlling the space segment capacity assignment among the various users. This center would process requests for service, monitor the links to ensure quality, terminate the

links at completion of the service, and return the capacity to the shared pool for reuse by others.

(6) Video conference control. Such conferences frequently involve several users at widely separated locations, and it is most economical for all to share a common video link that is reassigned on command by a conference coordinator. Thus a control capability linked to the corporate business communications network center and able to be operated at various sites is most desirable for conducting video conferences. Voice communications links associated with the conference would be operated in a broadcast mode so that all participants are always fully connected. The design of the ACTS system can handle all these link requirements. The master control station could act as the communications control center for the business communications experiments such as those described here.

Packet communications.—The ACTS system can support experimental studies of packet communications on satellites by means of its onboard baseband processor. Experiments may be operated either in a circuit-switched manner or over stationary preassigned channels used in a random-access TDMA (slotted ALOHA) manner. In the circuit-switched mode a 64-kbps channel is set up in each direction between the origin and the destination channel via the ACTS baseband processor. The stored messages are controlled from the ground by the master control station using a high-rate data link to the satellite. This permits network control of onboard packet communications experiments from the ground via the orderwire links between the sending and receiving nodes and the baseband processor. The various steps needed to accomplish packet communications with this arrangement are as follows:

- (1) Receive and store the packet at the ground terminal.
- (2) Request satellite forward and return channels to the destination from the master control station via orderwire.
- (3) Establish the channels through the baseband processor and transmit the packets by using an X.25 packet protocol equipped for satellite transmission.

Stationary preassigned routes for random-access TDMA.—Permanent channels are established via the ACTS multibeam communications package that connect uplink beam dwells to downlink beam dwells. These channels are then accessed by the ground terminals in a random-access, TDMA-basis packet communications mode. Figure 13 illustrates the connection of an uplink channel from each of four beam dwell regions (D_1 , D_2 , D_3 , and D_4) to four downlink channels in one downlink beam—in this case beam dwell region D_1 . The individual channels are designated by pairs of numbers, the first denoting the dwell region and the second, the channel number in that dwell. The same connectivity pattern can be repeated for any number of downlink beams. If the hopping beam system has N dwell regions that are visited in each 1-ms TDMA frame and it is desired to interconnect all N in a random-access TDMA manner, N uplink channels will be assigned in each uplink dwell (one destined to each of N downlink dwells), and N downlink channels will be assigned in each downlink dwell. This results in a total of N^2 channels to support the system. Such a configuration can carry

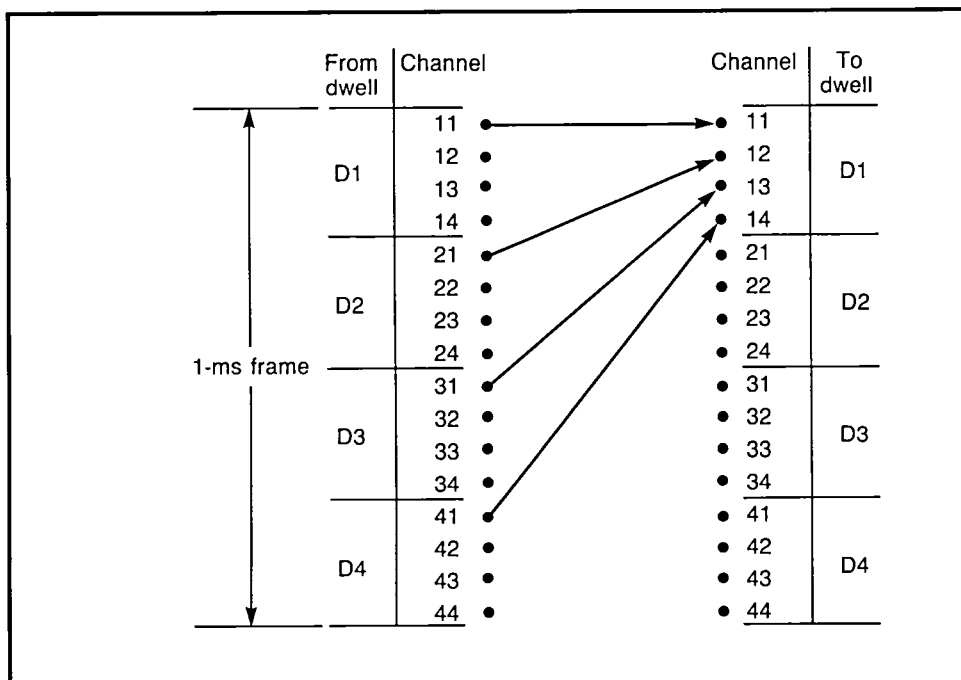


Figure 13.—Preassigned routes for random-access TDMA.

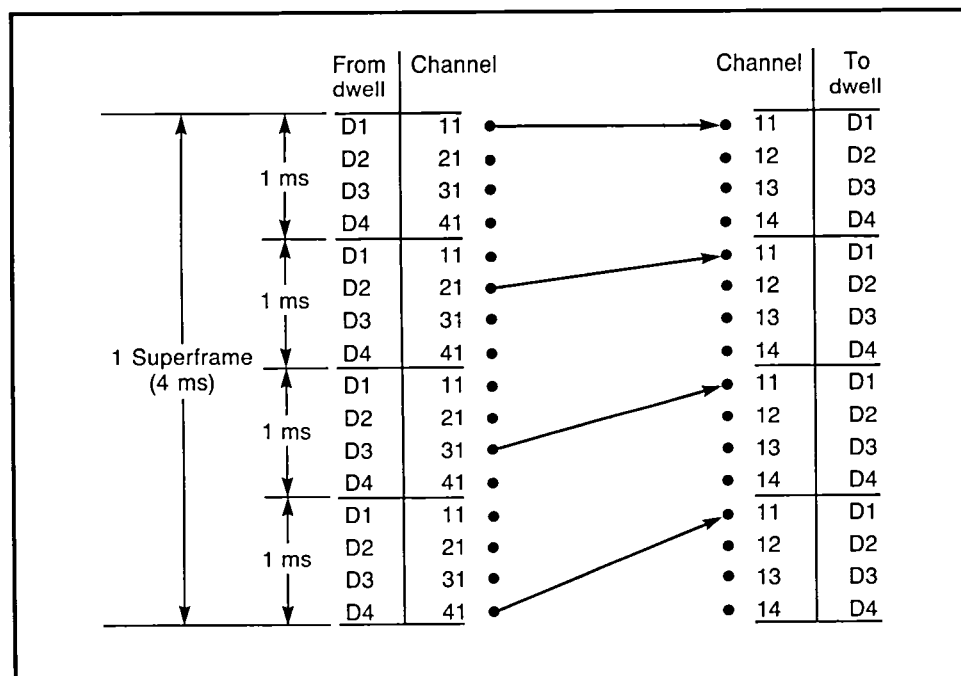


Figure 14.—Preassigned routes for single downbeam dwell.

approximately 20 percent of the maximum available capacity in the form of random packets synchronized to TDMA slot boundaries. Hence the throughput capacity of the system would be $0.2N \times 64$ kbps. Assuming that $N = 20$ and that each transaction requires a 1-kilobit packet in the forward direction, the configuration would support 40 000 transactions per day.

A node-hub arrangement in which uplinks from several dwell regions are routed to only one downlink in a destination dwell region containing the hub is obviously possible. A return link must be provided to all sending nodes from the dwell region containing the hub, and this can be accomplished by broadcasting the uplink from the hub's dwell to dwells containing the nodes.

Stationary preassigned operation can also be configured to provide the uplink channels in a time-sequential manner in a superframe. This permits operation of random-access TDMA with a lesser commitment of total capacity than does the configuration described in the previous paragraph. A single downlink channel in a destination dwell region is time-division multiplexed among the uplink beam dwells in a superframe, as shown in figure 14. This pattern can be repeated for a downlink in each destination dwell to achieve full interconnectivity by using the capacity of N channels. Such a configuration is shown in figure 15 for $N = 4$.

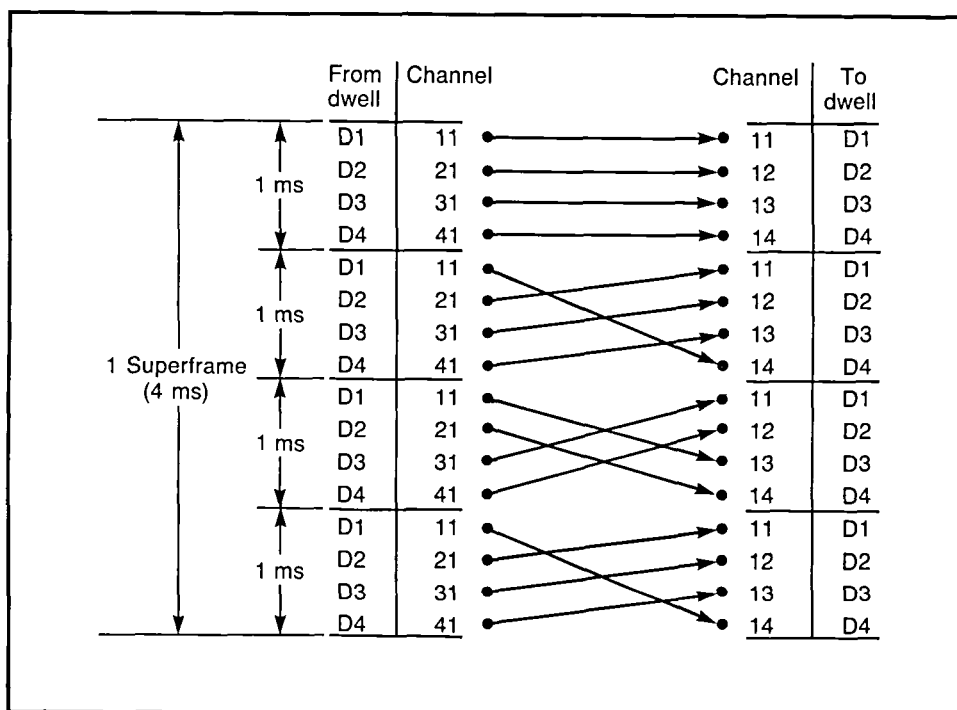


Figure 15.—Preassigned routes in superframe for random-access TDMA.

System Experiments

Baseband processor terminal acquisition and synchronization.—The first actions to be performed by a terminal entering the ACTS baseband processor network, acquisition and synchronization, are performed with the cooperation of the NASA master control station. After the terminal has completed this process, it is assigned uplink and downlink locations in the TDMA frame of sufficient duration to accommodate its traffic load. The terminal is then able to commence operational service. Traffic is transmitted in the form of a single uplink burst and a single downlink burst in each 1-ms frame. Each uplink burst will contain a number of 64-kbps traffic channels that are sent to corresponding destination terminals via downlink TDMA bursts.

To accomplish acquisition and synchronization, a terminal must perform the following steps:

- (1) Inform the NASA master control station that the terminal wishes to enter the frame. This is accomplished by prearranged scheduling. The master control station responds by programming the baseband processor to send a receiving acquisition burst (RAB) in the appropriate beam dwell interval, addressed exclusively to the terminal requesting entry. This burst is in addition to a reference burst that marks the start of the beam dwell and is used by all terminals that have completed acquisition and are carrying traffic.
- (2) The entering terminal enters a receive-only search mode that terminates when the synchronization to the RAB is accomplished.
- (3) Using a “start of frame” delay compensation value computed by the master control station for the location of the entering terminal and sent in the RAB orderwire, the entering terminal sends a transmitting acquisition burst (TAB).
- (4) The entering terminal adjusts its TAB delay until synchronization with an aperture programmed in the onboard baseband processor at the satellite is indicated in the tracking error word transmitted from the satellite as part of the RAB.
- (5) The terminal next determines the TAB location responsible for synchronization with the satellite and repositions its TAB to that location. It then examines the tracking error word to verify synchronization and maintains synchronization by obeying the early/late corrections given in the word.
- (6) The now-synchronized traffic terminal sends a message on its TAB orderwire declaring successful synchronization. This message is relayed to the master control station via the baseband processor’s orderwire burst.
- (7) Using the RAB orderwire, the master control station acknowledges the declaration of synchronization by sending the traffic terminal a position offset delay value that is used to shift the receiving timing of the terminal to the reference burst. The reference burst contains both the tracking error word messages so that it can maintain traffic burst synchronization and the outbound orderwire so that it can receive messages from the master control station. Using

the outbound orderwire, the master control station sends the information needed by the terminal to locate its transmitting and receiving traffic bursts and configure its channels.

(8) To complete the entry process, the master control station commands a synchronous change in the burst time plan that permits the traffic terminal to move its traffic burst to its assigned position and start transmitting. Any further instructions to the traffic terminal regarding traffic reconfiguration are sent via the reference burst's orderwire.

The acquisition and synchronization process described here comprises a chain of processes each of which will be the subject of experimental testing to evaluate its performance. Such testing should seek to experimentally determine and gain experience with the parameter tolerance limits (such as bit error rate, Doppler, and timing uncertainty) within which the process can be expected to function such that acceptable operational performance is ensured. Processes and circumstances that need such evaluation are

- (1) RAB search and acquisition
- (2) TAB search and acquisition
- (3) Timing jitter induced by the tracking error word tracking loop
- (4) Synchronization transfer between reference and receiving acquisition bursts
- (5) Synchronous burst time plan execution
- (6) Effect of undetected errors in the orderwire and tracking error word
- (7) Effect of the loss of orderwire continuity due to fades

Demand assignment of capacity to traffic.—Once a traffic terminal has achieved a synchronized status, it may proceed to establish traffic channels. To do this, it must send to the master control station, via the inbound orderwire contained in its traffic burst preamble, a request message that identifies the capacity of each desired channel and its destination. The master control station, using its algorithm for a traffic burst and beam dwell time plan, determines several parameters. These are the time coordinates of burst position, burst duration, uplink and downlink hopping beam dwell epochs, individual channel baseband processor switch connections, and individual channel locations within the burst for the uplink (transmitting side) and downlink (receiving side) TDMA bursts of the requesting terminal. The latter coordinates are sent to the baseband processor by using the master control station's control burst, which contains baseband processor control directives and outbound orderwire channels. Those time coordinates needed to control the onboard processing, switch, and beam dwell programs are demultiplexed and stored as appropriate. Those needed to control the requesting traffic terminal are formatted on the reference burst's outbound orderwire for the beam dwell containing the terminal. When these have been sent and acknowledged, the system is ready to execute a synchronous burst time plan change that will invoke the new traffic burst, beam hopping, onboard processing, and onboard switching time plans.

A synchronous burst time plan is accomplished as follows: The master control station identifies on the outbound orderwire a frame number on which the new time plan is to be invoked by all network terminals. The frame numbers are carried in the master control station's control burst transmitted from the NASA ground station and relayed in the reference and receiving acquisition bursts on the downlinks. When this frame number is observed by all terminals, they activate the new downlink (receiving side) time plan. The new uplink (transmitting side) time plan is activated M frames later, where M denotes the coordination time, the smallest integer number of TDMA frame periods that exceeds the roundtrip propagation between the satellite and the farthest ground terminal. A few additional frame periods are appended to this value to allow for processing time. A similar procedure is used on the satellite to activate the new receiving and transmitting processing and beam hopping time plan. Time plan changes pertaining to the uplink are activated on the identified frame number and two frames later on the downlink side.

From this description it is clear that assignment of capacity depends on the successful completion of a chain of message exchanges involving the ground terminal requesting the capacity; the onboard processing, switching, and beam hopping system; the master control station; and the destination terminal. Experiments can be performed for the following reasons:

- (1) To explore the limits of successful operation by stress testing the link and monitoring the bit error rate
- (2) To investigate the speed of response to originating traffic requests under varying conditions of traffic load
- (3) To develop the experience base needed to evolve operational procedures for commercial applications
- (4) To investigate user end-to-end performance measurements

Call processing.—The call processing included in ACTS is designed to establish channels on a call-by-call demand-assigned multiple access basis. At the beginning of a call the digits of the call destination are intercepted at the interface to the ground terminal and sent to the master control station over the inbound orderwire. The special message format assigned to the call setup function is used. At the master control station a table is referred to that identifies the destination station nearest the call destination and generates all functions needed to achieve the end-to-end connection required to carry the call. Using the outbound orderwire, the master control station sends the call coordinates to the satellite. The satellite receives and stores the onboard coordinates to prepare for the uplink-to-downlink connection. It then sends the uplink and downlink traffic burst coordinates over the downlink outbound orderwire to all ground terminals, where they are received and stored to prepare for the connection. At the frame number identified by the master control station the coordinates are executed by using the synchronous time plan change procedure, and the requested connection is completed between the origin and destination ground terminals.

At the destination ground terminal the call destination digits are forwarded to a switch that completes the call by conventional signaling and supervision procedures. Call completion is signaled by the on-hook supervisory condition sensed by the terminal at the disengaging end. The master control station is informed by a message sent from the disengaging end via the inbound orderwire. The master control station then formats messages to all terminals and the satellite onboard processor to prepare for disengaging the call. At a frame number designated by the master control station, the reconfigured switch executes another synchronous burst time plan change procedure, and the call is disengaged.

The call processing function of ACTS involves the interaction of distributed system components accomplished by the transmission of call setup and disengagement messages sent over the orderwires. This is another area in which much experience is needed in order to establish operating procedures. The following elements require further investigation during the experimental ACTS Program:

- (1) Development of algorithms that rapidly identify the traffic burst and onboard processing and switching coordinates to set up end-to-end connections
- (2) Development of packet message structures and protocols that rapidly accomplish the call setup and disengagement without error
- (3) Experimental and analytical testing and evaluation of adopted procedures to discover any protocol errors or omissions
- (4) Experimental and analytical investigation of the performance of call processing under stress conditions on the transmission link
- (5) Development of automatic checks and background diagnostics to ensure that the call processing system is in operating condition and to identify equipment failure
- (6) Development, testing, and evaluation of switchover, without interference to traffic under way, to a redundant central call processing facility when the on-line processor fails

Application of fade compensation.—ACTS is able to combat both uplink and downlink fades. Transmitting power control is used for high-burst-rate operation. A combination of symbol rate reduction and coding on the uplinks and downlinks is used for low-burst-rate operation.

The principal source of low-burst-rate fade protection is the combination of bit rate reduction, which provides 6 dB of signal gain, and coding, which provides another 4 dB of signal gain. However, it requires a four-to-one expansion in the link capacity for the channels affected by the fade. Thus a way is required to call up such capacity on demand when it is needed. One way, which is being used on ACTS, is to set aside in the TDMA frame a pool of capacity that can be assigned to the links affected by a fade. Thus when a fade is sensed, ACTS will be able to reassign its capacity. This must be accomplished before the fade reaches a depth sufficient to cause serious impairment. Another possible way is to invoke a source coding strategy that temporarily reduces the source rate by four to one,

thus making it possible to carry the coded channels in the same channel space and avoiding the need for reserve capacity. This latter technique was discussed earlier.

The capability to assign coding on demand in ACTS provides an opportunity for experimental involvement by the users. Some suggestions are listed here:

- (1) Experimentation with fade detection algorithms that are able to sense the onset of fades with minimum false alarms
- (2) Experimentation with strategies for rapidly accessing the reserve
- (3) Experimentation with the combination of source coding and channel coding to eliminate the need for holding capacity in reserve
- (4) Experimentation with reserve capacity assignment algorithms (used to rapidly invoke coding on channels affected by fades) and their relationships to the traffic burst and onboard processing and switching time plans.
- (5) Operational service demonstrations of ACTS fade-combating capabilities

Operational telephone.—ACTS ground terminals are nominally equipped with interfaces that can accept a T-1 digital rate of 1.544 Mbps. Each of the T-1's twenty-four 64-kbps pulse-code-modulated telephone channels can be routed to different destinations, or all 24 channels can be routed to a single destination, thus providing a composite rate of 1.544 Mbps. Other rates can be routed over the system by aggregating blocks of 64-kbps channels. If the rate is not an integer number of channels, 8-kbps fractions of a channel can be used, but an entire channel must be assigned to carry such fractions. Interfaces at rates that are multiples of the T-1 rate, such as T-3, could be implemented by the user.

By using this ACTS capability, telephone companies can implement inter- and intra-LATA (local-access transport area) satellite links for carrying a wide variety of digital telephone services such as those listed here:

- (1) High-bit-rate data
- (2) Integrated-services digital network
- (3) Digital video teleconferencing, either point to point or point to multipoint and either preassigned or demand assigned
- (4) Thin-route, demand-assigned multiple access telephone
- (5) Trunk telephone

These communications services can be established by using portable terminals to provide quick reaction to customers' demands or to meet flexible telephone company services that are needed for short intervals anywhere in the ACTS low-burst-rate coverage

Scientific Experiments

Propagation.—On ACTS there are two beacons, one at the uplink frequency of 27.5 GHz and the other at the downlink frequency of 20 GHz. These signals are linearly polarized with broad CONUS coverage. Each produces a nominal clear-sky carrier-to-noise-density ratio of approximately 52 dB/Hz into a 3-m-diameter antenna having a gain-to-noise-temperature-ratio of 21.2 dB/K. For a 1.8-m-diameter antenna with the same low-noise amplifier, the carrier-to-noise-density ratio would be reduced to 47.5 dB/Hz. By using a fade processor with a carrier level detection bandwidth of 1 Hz, it is possible to observe fades to depths of 42 dB with a 3-m-diameter antenna and 39 dB with a 1.8-m-diameter antenna.

Ground terminals to be used in the ACTS system can be equipped with fade processors that will detect the received levels from the two beacons and send the data over orderwire channels to the master control station, where they will be archived in a data base. These data can be made available to investigators for study and evaluation. This feature could make available 20- and 30-GHz fade information on a wide scale in time and space within the coverage pattern of the high- and low-burst-rate antenna systems. Propagation data collected from ACTS could be used to further quantify the characteristics of Ka-band satellite service. Propagation features that can be examined include correlation between fading at 20 and 30 GHz at the same site, correlation of fades at spatially separated sites, and determination of correlation distance, fading rates, and probability distribution functions of fade depth. A radiometric receiver would also be available to determine the atmospheric noise temperature, a means to measure rainfall rate in the propagation path, and a means to collect these data in the same time relationship as the fade data.

An important feature of ACTS is its capability to invoke coding and augment power on fading channels. This must be done fast enough to prevent loss of communications during the process. This feature affords a challenging opportunity not only to collect important propagation data, but also to apply the information in an active way to improve link quality. Many study and experiment opportunities for investigations are opened up by the existence of this unique capability within ACTS.

Source coding used adaptively with rain fade channel coding.—Source coding refers to the process of removing information from the source signal that is used either inefficiently or redundantly. Accordingly source coding reduces the channel information rate needed to transmit the remaining signal information. Many techniques for performing source coding on speech and video signals are available. Its use significantly reduces the bit rate needed to carry speech, making it possible to communicate with small, low-power terminals. Adding channel coding further improves performance by 4 to 5 dB, making possible further reduction in ground terminal size.

For speech the normally accepted information rate for telephone quality is 64 kbps. Even for this rate, source coding that employs instantaneous logarithmic amplitude companding is used. The benefits of speech source coding are

extended by time-assignment speech interpolation (TASI), which uses the silences that punctuate conversation to carry the speech spurts of other conversations. TASI achieves an approximate two-to-one reduction, yielding an average rate of 32 kbps per circuit. This process works best when more than 30 conversations are carried. Another technique achieving a two-to-one reduction is adaptive differential pulse code modulation (ADPCM). Both techniques have been or are now being applied to commercial telephone service, either separately or combined. Combining the techniques reduces the overall source coding rate by a factor of 4.

As described earlier, ACTS uses channel coding to improve link performance when severe fades occur, and this requires that the transmission rate on the link be expanded by a factor of 4. If this expansion is coupled to the application of source coding having a reduction factor of 2 by using either of the previously described source coding methods, the transmission expansion would be reduced to a factor of 2. If the two source coding methods are combined to achieve a source coding reduction of 4, the need for expansion would be eliminated. This greatly simplifies use of adaptive channel coding to improve link performance since no additional channel bandwidth is required.

Similar source coding opportunities exist for video signals. This is evidenced by the availability of coders/decoders for full-motion video conferences and freeze-frame video at information rates ranging from 56 kbps to 1.544 Mbps. Provided that the source coder can be signaled when to shift to the lower rate, this capability can obviously be used to reduce or eliminate the transmission rate expansion needed for adaptive channel coding. These source coders may impair quality slightly when used in this manner, but this is a small price to pay for the communications continuity achieved.

ACTS, with its unique capability to adaptively invoke channel coding when it is needed to combat rain fade, provides an equally unique opportunity to apply source coders adaptively in order to facilitate the process. Ample opportunity exists for experimenters to study and demonstrate the combination of source and channel coding in this application.

Appendix—Acronyms



ACTS	Advanced Communications Technology Satellite
ADPCM	adaptive differential pulse code modulation
ALOHA	a contention-based access method
BBP	baseband processor
BER	bit error rate
BFN	beam forming network
CONUS	continental United States
CR&T	command ranging and telemetry
DAMA	demand-assigned multiple access
DRP	digital routing processor
EIRP	effective isotropic radiated power
EOF	end of frame
F	frame
FDM	frequency-division multiplexed
FDMA	frequency-division multiple access
FEC	forward error correction
GEO	geostationary Earth orbit
HBR	high burst rate
IF	intermediate frequency
LATA	local-access transport area
LBR	low burst rate
LEO	low Earth orbit
MSM	microwave switch matrix
NASA	National Aeronautics and Space Administration
QPSK	quadrature phase shift key
RAB	receiving acquisition burst
SMSK	serial minimum shift key
SOF	start of frame
TAB	transmitting acquisition burst
TASI	time-assignment speech interpolation
TDM	time-division multiplexed
TDMA	time-division multiple access
TWT	traveling-wave tube
VSAT	very small-aperture terminal



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